U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-123565

Assessment of Energy Resource Development Impact on Water Quality: The Belle Fourche and Little Missouri River Basins

(U.S.) Environmental Monitoring and Support Lab., Las Vegas, NV

Oct 79

United States
Environmental Protection
Agency

Environmental Monitoring
and Support Laboratory
P.O. Box 15027
Las Vegas NV 89114

EPA-600/7-79-234
October 1979

Research and Development

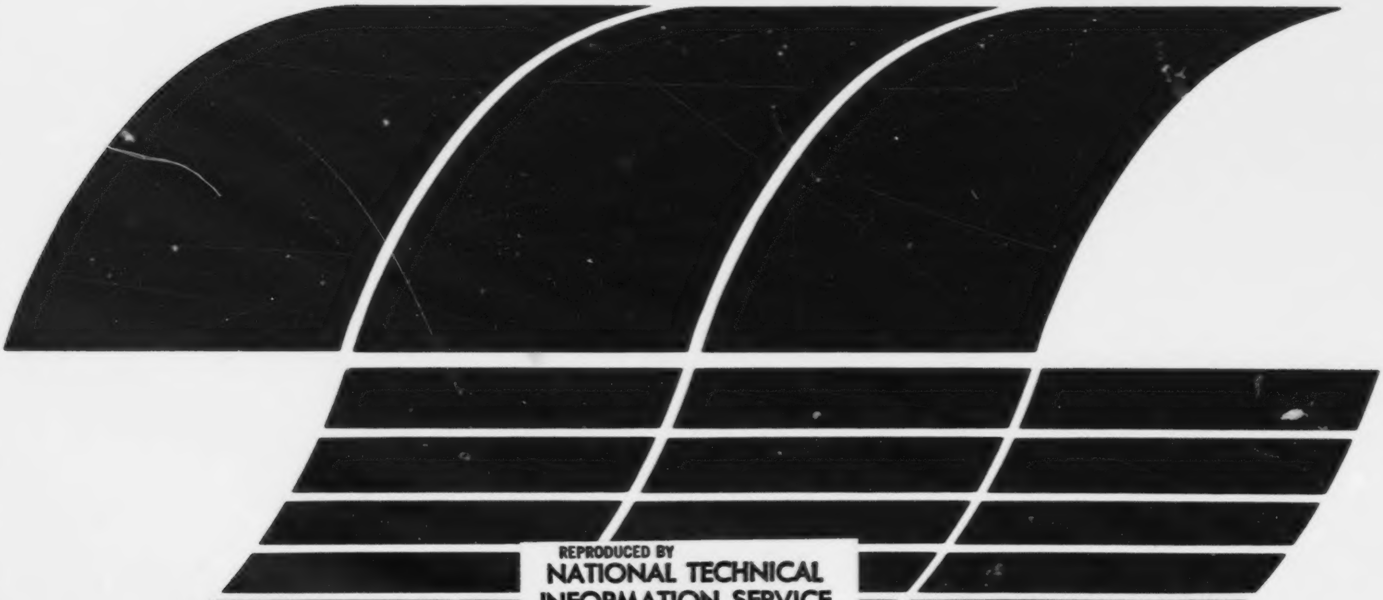
PB80-123565

EPA

Assessment of Energy Resource Development Impact on Water Quality:

The Belle Fourche and Little Missouri River Basins

Interagency Energy-Environment Research and Development Program Report



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY—ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA'S mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-234	2.	3. RECIPIENT'S ACCESSION NO. PB 80-123565

4. TITLE AND SUBTITLE ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY: The Belle Fourche and Little Missouri River Basins	5. REPORT DATE October 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) S.M. Melancon*, B.C. Hess, and R.W. Thomas *University of Nevada, Las Vegas, NV	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, and Biology Department, University of Nevada, Las Vegas, NV	10. PROGRAM ELEMENT NO. INE625 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency-Las Vegas, NV Office of Research and Development Environmental Monitoring and Support Laboratory Las Vegas, NV 89114	13. TYPE OF REPORT AND PERIOD COVERED Final to 1978 14. SPONSORING AGENCY CODE EPA/600/07

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The Belle Fourche and Little Missouri River Basins are key areas in the Nation's search for untapped resources to supplement increasing energy demands. The basins contain vast beds of low-sulfur, strippable coal that potentially will support a large number of coal-fired powerplants and gasification and liquefaction complexes for conversion of coal into commercially usable power. However, utilization of these energy resources, especially if maximum levels of expansion are realized, is expected to have considerable impact on water resources in the Little Missouri and Belle Fourche River Basins. It appears unlikely that there are sufficient surface or ground-water supplies to meet projected needs in the area without creation of additional reservoir storage and or diversion of surface water via aqueducts from other sources. Decreased flows from energy developments will accompany increased salt and sediment loadings. The resultant lowered water quality will further reduce water usability for municipal, industrial and irrigation purposes and will have adverse impacts on the aquatic ecosystem. Water quality monitoring needs in the basins are addressed with priority listings of parameters for measurment to detect changes in water quality as a result of energy resource development, and through definition of those U.S. Geological Survey sampling stations that are best situated for monitoring activities.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water resources Water pollution	Monitoring 17B Little Missouri River Belle Fourche River Basin Coal Strip mining	08H 13B 48A 68D

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 178
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 — 683-091/2207

EPA-600/7-79-234
October 1979

ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY
The Belle Fourche and Little Missouri River Basins

by

S. M. Melancon
Biology Department
University of Nevada, Las Vegas
Las Vegas, Nevada 89154
and
B. C. Hess and R. W. Thomas
Monitoring Operations Division
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada 89114

ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89114

DISCLAIMER

This report has been reviewed by the Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific data. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment, and

- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs.

This report presents an evaluation of surface water quality in the Little Missouri and Belle Fourche River Basins and discusses the impact of energy development upon water quality and water availability. The water quality data collected to date and presented in this report may be considered baseline in nature and used to evaluate future impacts on water quality. This report was written for use by Federal, State, and local government agencies concerned with energy resource development and its impact on western water quality. Private industry and individuals concerned with the quality of western rivers may also find the document useful. This is one of a series of reports funded by the Interagency Energy-Environment Research and Development Program. For further information contact the Water and Land Quality Branch, Monitoring Operations Division.

George B Morgan

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

SUMMARY

Development of fossil fuel, uranium, and other energy reserves located in the Western United States is considered essential. These resources are located primarily in the Northern Great Plains and the Colorado Plateau. Because of our national dependence upon oil and gas, conversion of coal to these liquid and gaseous forms is anticipated.

Development of these resources cannot be accomplished without some environmental impact. The potential for serious degradation of air, land, or water quality exists. Pollution may occur during any or all stages of the extraction, refining, transportation, conversion, or utilization processes. Secondary impacts resulting from increased population pressures, water management, and development of supportive industries are expected. Potential contamination of ground-water supplies from in situ coal conversion facilities, and nonpoint pollution from sources such as stack emissions, airborne dust, and localized "spills", are of particular concern in the Little Missouri and Belle Fourche River Basins. With careful planning and regulation, such impacts can be minimized and held within tolerable levels.

The primary objective of this report is to evaluate the existing water quality monitoring network in the Little Missouri and Belle Fourche River Basins and to recommend needed modifications to the present sampling program. As a basis for these recommendations, known developments, both present and planned, are discussed and available data examined. The impact of developers on both water quality and quantity, particularly related to coal strip mining activities in the vicinity of Gillette, is defined.

A monitoring network designed to detect trends in surface water quality is proposed on the basis of our present knowledge. Such a network minimizes the number of observations at the expense of the number of stations in order to provide statistically valid data. This network consists of twelve stations:

USGS Station#	Description
06425720	Belle Fourche River below Rattlesnake Creek, WY
06426400	Donkey Creek near Moorcroft, WY
06426500	Belle Fourche River below Moorcroft, WY
06428500	Belle Fourche River at WY-SD State line
not established	Belle Fourche River above Whitewood Creek, SD
not established	Whitewood Creek at mouth, SD
06437000	Belle Fourche River near Sturgis, SD

USGS Station #	Description
06438000	Belle Fourche River near Elm Springs, SD
06334000	Little Missouri River near Alzada, MT
06335500	Little Missouri River at Marmarth, ND
06336000	Little Missouri River at Medora, ND
06337000	Little Missouri River near Watford City, ND

A similar network for ground-water monitoring needs to be implemented; however, presently available data are insufficient to adequately determine station locations.

Biological, physical, and chemical parameters likely to be affected by energy resources development activities were determined. Salinity and suspended sediment concentrations are already a problem in both study basins, and a number of trace elements are found in prohibitively high concentrations in the Belle Fourche River below the Homestake Mine in South Dakota. Physical and chemical parameters recommended as top priority for monitoring are:

Total alkalinity
Total aluminum
Total arsenic
Bicarbonate
Biological oxygen demand of bottom sediments
Total boron
Total cadmium
Total organic carbon in bottom sediments
Dissolved calcium
Chloride
Total chromium
Specific conductance
Total copper
Total cyanide
Flow
Fluoride
Total iron
Total lead
Dissolved magnesium
Total manganese
Total mercury
Total molybdenum
Dissolved oxygen
Total nickel
Nitrate-nitrite-N
Pesticides
Petroleum hydrocarbons
pH
Total phosphorus
Dissolved potassium
Total selenium
Dissolved sodium
Dissolved sulfate
Suspended sediments
Temperature
Total dissolved solids

Biological monitoring is considered to be presently the most feasible method of assessing the impact of the introduction of an extensive number of organic chemicals into the environment such as may result from in situ coal conversion activities. Those biological analyses recommended as having top priority for monitoring water quality in the Belle Fourche and Little Missouri River Basins include:

Macroinvertebrates - Counts and identifications, biomass
Periphyton - Biomass, growth rate, identification, and relative abundance determinations
Fish - Identification and enumeration, toxic substances in tissue

Macrophytes - Species identification and community association
Zooplankton (lentic only) - Identification and count
Phytoplankton (lentic only) - Chlorophyll a, identification, and enumeration
Microorganisms - Total fecal coliform

In order to obtain sufficient data for trend analyses, collection of physical/chemical parameters on a weekly basis at the Little Missouri station at Watford City and the Belle Fourche station at Elm Springs is recommended. If resources permit, the Belle Fourche station near Moorcroft should also be sampled weekly. All other priority stations should collect physical/chemical data on a monthly basis to provide spatial distribution data. Sediment samples should be collected on a monthly basis, and biological samples on a seasonal or semiannual basis (except for monthly bacteriological analyses). Semiannual water samples for organic analyses are recommended.

In both the Little Missouri and Belle Fourche River Basins, water availability will be the major factor limiting future development of energy resources. An inventory of all water right allocations in these basins, as well as mean annual consumptive use of surface waters, is recommended. Such an inventory would provide comprehensive data for the four States affected by the river drainages and provide a basis for future decisions in water right assignments. Establishment of enforceable minimum instream flow requirements in both basins is also recommended in light of the anticipated impact to fisheries and recreation activities during low water years as a result of increasing energy development.

CONTENTS

Foreword iii
Summary iv
Figures viii
Tables ix
1. Introduction 1
2. Conclusions 3
3. Recommendations 5
4. Study Area 7
Geography 7
Water resources 18
Water uses 22
Fish and wildlife resources 23
Mineral resources 26
5. Energy Resource Development 30
Active development 30
Proposed development 39
Transportation of energy resources 41
6. Other Sources of Pollution 46
Erosion 46
Mine drainage 47
Urban runoff 48
7. Water Requirements 49
Water rights 49
Water availability 50
Little Missouri and Belle Fourche River withdrawals 53
Importation of water 62
Water availability versus demand 62
8. Water Quality 64
Sources of data 64
Summary of physical and chemical data 64
Impact of development on surface water 64
Impact of development on ground water. 83
9. Assessment of Energy Resource Development 89
Impact on water quantity 89
Impact on water quality 90
10. Recommended Water Quality Monitoring Parameters 92
Physical and chemical parameters 92
Biological parameters 100
11. Assessment of Existing Monitoring Network 109
References 114

Appendices

A. Conversion factors 120
B. Chemical and physical data 122
C. Parameters exceeding water quality criteria 155

FIGURES

Number Page

1 Location of the Little Missouri and Belle Fourche River Basins 8

2 The geologic structure of the Little Missouri and Belle Fourche River Basins 11

3 Generalized surface outcrops of the geologic formations in the Little Missouri-Belle Fourche study area 14

4 Federal, State, and other land areas in and around the Belle Fourche and Little Missouri River Basins 17

5 Map of mineral resources in the Black Hills area of Wyoming and South Dakota 28

6 Location of oil fields around the Little Missouri River Basin, North Dakota 31

7 Location of the East Gillette Mine and 14 other operating, proposed, or anticipated coal mines involving Federal coal leases in Campbell County, Wyoming 33

8 Unit coal energy to be transported from the Western United States by the year 2000 42

9 High Btu gas liquid (crude oil, shale oil, coal syncrude) pipelines proposed by the year 2000 for the Western United States 44

10 Electricity expected to be transported from the Western United States by the year 2000 45

11 Mean monthly variations in streamflow in the Belle Fourche River in Wyoming 51

12 Proposed alternatives for the importation of water to the Gillette, Wyoming, coal mine development area 63

13 Location of U.S. Geological Survey water quality sampling stations in the Belle Fourche and Little Missouri River Basins 66

TABLES

Number Page

1 Summary of Total Projected Annual Energy Production Levels from Advanced Sources 2

2 Climatic Data for the Belle Fourche River Basin 9

3 Generalized Geological Stratigraphic Sequence in the Little Missouri and Belle Fourche River Basins 13

4 Major and Minor Population Centers in the Little Missouri and Belle Fourche River Basins, 1970 Census 15

5 Estimated Area in Major Land Use Categories for the Little Missouri and Belle Fourche River Basins 19

6 Existing Reservoirs and Lakes in the Belle Fourche-Little Missouri Study Area 20

7 Proposed Reservoirs on the Little Missouri River 21

8 Ground-Water Formations Known to Occur in the Little Missouri and Belle Fourche River Basins, Northeastern Wyoming 21

9 Percentage of Total Water Withdrawals and Water Consumed in the Little Missouri-Belle Fourche River Study Area That are Associated With Various Beneficial Uses, 1965 24

10 Fish Species Known to Occur in the Little Missouri and Belle Fourche River Basins 25

11 Types of Mineral Resources in the Belle Fourche-Little Missouri River Basins Study Area 26

12 Mineral Resources Other Than Coal Located in the Black Hills Area of Wyoming and South Dakota 27

13 Total Oil Production for Counties in the Little Missouri River Basin, North Dakota, 1976 30

14 Mining Plan for the Belle Ayr Mine, Belle Fourche River Basin 34

Number Page

15 Proposed Gasification-Liquefaction Plants in or near the Belle Fourche-Little Missouri River Basin Study Area 40

16 Anticipated Water Requirements for Energy Facilities in the Little Missouri-Belle Fourche Study Area in the Year 2000 41

17 Major Potential Elemental Pollutants Associated With Coal Mining Activities in the Little Missouri and Belle Fourche River Basins 47

18 Estimated Annual Water Yield, Consumptive Use, and Evaporative Loss of Surface Waters in the Belle Fourche and Little Missouri River Basins, Wyoming, 1948-68 52

19 Summary of Average Annual Water Use in the Little Missouri River Basin, South Dakota 53

20 Water Use for Coal-Related Activities 54

21 Approximate Area and Annual Water Use for Irrigation in the Belle Fourche and Little Missouri River Basins 56

22 Major Existing Reservoirs Used Primarily for Irrigation Purposes in the Little Missouri-Belle Fourche Study Area 57

23 Domestic and Municipal Waste Treatment Facilities in the Little Missouri and Belle Fourche River Basins 58

24 Industrial Dischargers in the Little Missouri and Belle Fourche River Basins 59

25 Projected Average Annual Livestock Water Use in the Western Dakota Subbasin 61

26 U.S. Geological Survey Water Quality Sampling Stations in the Little Missouri and Belle Fourche River Basins 65

27 Distribution of Major Cations and Anions at Selected Stations in the Little Missouri and Belle Fourche River Basins, 1972 and 1977 68

28 Water Quality in Donkey Creek, Wyoming, below Wyodak and near Rozet, June 1975 70

29 Water Quality Criteria Recommended by the National Academy of Sciences 71

30 Sawyer's Classification of Water According to Hardness Content. 72

Number Page

31 Total Dissolved Solids Hazard for Irrigation Water 73

32 Total Dissolved Solids Hazard for Water Used by Livestock. . . . 74

33 Maximum Total Dissolved Solids Concentrations of Surface Waters Recommended for Use as Sources for Industrial Water Supplies 75

34 Parameters Exceeding EPA or National Academy of Sciences Water Quality Criteria, 1970-78, at U.S. Geological Survey Stations in the Little Missouri and Belle Fourche River Basins 77

35 Recommended Revisions of 1975 NPDES Permit Limitations for Trace Element Discharges from the Homestake Mine 78

36 U.S. Environmental Protection Agency Drinking Water Regulations for Selected Radionuclides 80

37 A Partial Listing of Ground-Water Sources in Northeastern Wyoming. 84

38 Chemical Characteristics of a Number of Ground-Water Aquifers in the Little Missouri and Belle Fourche River Basins, Wyoming and South Dakota 86

39 Availability and Quality of Ground Water by Basin and Time-Rock Unit in Northeastern Wyoming 87

40 Priority I, Must Monitor Parameters for the Assessment of Energy Development Impact on Water Quality in the Little Missouri and Belle Fourche River Basins 94

41 Priority II, Parameters of Major Interest for the Assessment of Energy Development Impact on Water Quality in the Little Missouri and Belle Fourche River Basins 97

42 Priority III, Parameters of Minor Interest That Will Provide Little Useful Data for the Assessment of Energy Development Impact on Water Quality in the Little Missouri and Belle Fourche River Basins 98

43 Priority I Biological Parameters Recommended for Monitoring Water Quality in the Little Missouri and Belle Fourche River Basins 103

44 Priority II Biological Parameters Recommended for Monitoring Water Quality in the Little Missouri and Belle Fourche River Basins 106

Number Page

45 Selected Parameters Monitored by the U.S. Geological Survey in the Belle Fourche and Little Missouri River Basins and their Average Annual Frequency of Measurement 111

46 U.S. Geological Survey Stations Recommended to Have the Highest Sampling Priority in the Little Missouri-Belle Fourche Study Area for Monitoring Energy Development 113

B-1 Dissolved Solids, Sum of Constituents, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 123

B-2 Conductivity, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 124

B-3 Dissolved Calcium, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 125

B-4 Dissolved Sodium, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 126

B-5 Dissolved Magnesium, 1971-78, at U. S. Geological Survey Sampling Stations in the Little Missouri River Basin 127

B-6 Dissolved Potassium, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 128

B-7 Bicarbonate Ion, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 129

B-8 Sulfate, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 130

B-9 Chloride, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 131

B-10 Dissolved Silica, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 132

B-11 Total Hardness, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 133

B-12 Temperature, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 134

B-13 pH, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 135

B-14 Total Alkalinity, 1971-78, at U.S. Geological Survey Sampling Stations in the Little Missouri River Basin 136

Number Page

B-15 Dissolved Solids, Sum of Constituents, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 137

B-16 Conductivity, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 138

B-17 Dissolved Calcium, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 139

B-18 Dissolved Sodium 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 140

B-19 Dissolved Magnesium, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 141

B-20 Dissolved Potassium, 1971-78, at U. S. Geological Survey Sampling Stations in the Belle Fourche River Basin 142

B-21 Bicarbonate Ion, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 143

B-22 Sulfate, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 144

B-23 Chloride, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 145

B-24 Dissolved Silica, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 146

B-25 Total Hardness, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 147

B-26 Total Iron, 1972-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 148

B-27 Total Manganese, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 149

B-28 Temperature, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 150

B-29 Dissolved Oxygen, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 151

B-30 pH, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 152

Number | Page
B-31 Total Alkalinity, 1971-78, at U.S. Geological Survey Sampling Stations in the Belle Fourche River Basin 153

B-32 Suspended Sediments, 1971-78, at Selected U.S. Geological Survey Sampling Stations in the Little Missouri and Belle Fourche River Basins 154

C-1 Parameters Exceeding Water Quality Criteria in the Belle Fourche and Little Missouri River Basins and The Total Number of Observed Violations 155

1. INTRODUCTION

This report is part of a multiagency study involving the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA), under various interagency agreements. The primary objective of this report series is to evaluate the existing water quality monitoring network in each study basin and to recommend needed modifications to the present sampling program design. As a basis for monitoring strategies recommended in this report, known energy developments, both present and planned, are defined and available baseline data in the Little Missouri and Belle Fourche River Basins are examined. For assessment of these monitoring strategies, the impact of ongoing and anticipated energy development on both water quality and quantity in the western energy basins is considered. Preliminary recommendations of key water quality parameters for surveillance of energy development impact are proposed. Future documents will present more detailed analyses of potential impacts from various energy technologies, sampling methodologies and frequency requirements, and site alternatives in light of updated information regarding water right allocations.

Throughout the 1950's, the United States was effectively energy self-sufficient, satisfying its needs with abundant reserves of domestic fuels, such as coal, oil and gas, and hydroelectric power. However, energy consumption has been increasing during the past ten years at an annual rate of 4 to 5 percent, a per capita rate of consumption eight times that of the rest of the world (Federal Energy Administration 1974). The Federal Energy Administration (1974) in the "Project Independence" report states that:

- By 1973, imports of crude oil and petroleum products accounted for 35 percent of total domestic consumption.
- Domestic coal production has not increased since 1943.
- Exploration for coal peaked in 1956, and domestic production of crude oil has been declining since 1970.
- Since 1968, natural gas consumption in the continental United States has been greater than discovery.

The United States now relies on oil for 46 percent of its energy needs, while coal, our most abundant domestic fossil fuel, serves only 18 percent of our total needs (Federal Energy Administration 1974). In light of the fact that we have only a few years remaining of proven oil and gas reserves, and to reduce our vulnerable dependency upon foreign oil, the Federal government is promoting the development of untapped national energy resources in anticipation of upcoming energy requirements. Included among these resources are the abundant western energy reserves. Over half of the Nation's coal reserves are located in the Western United States, as well as effectively all the uranium, oil shale, and geothermal reserves. The projected national annual production levels for some recently expanding energy sources through the year 2000 are presented in Table 1.

TABLE 1. SUMMARY OF TOTAL PROJECTED ANNUAL ENERGY PRODUCTION LEVELS FROM ADVANCED SOURCES (10^{15} joules per year) (modified from Hughes et al. 1974)

Source	1970	1975	1980	1985	1990	1995	2000
Solar	0	0	0	400	2,500	4,000	12,000
Geothermal	1.8	14	72	180	360	720	1,400
Oil Shale	0	0	610	2,000	2,700	3,400	4,000
Solid Wastes	0	10	55	300	950	3,000	10,000
Total	1.8	24	737	2,880	6,510	11,120	27,400
U.S. Demand	70,000	83,000	98,000	120,000	140,000	170,000	200,000
Percent of U.S. demand filled by above sources	$3x10^{-3}$	$3x10^{-2}$	0.8	2	5	6	13

In the Little Missouri and Belle Fourche River Basins, energy resource development will primarily be increased by strip mining of coal with construction of associated transportation facilities. Development of uranium reserves, oil and gas fields, and other resources will occur to a much lesser extent, as will construction of onsite coal-fired electrical generation facilities if increased water supplies become available. It is difficult to assess the extent and severity of degradation in environmental quality that can be expected from this development. However, one of the biggest impacts will undoubtedly result from competition for water resources created by growing demands of municipal, industrial, agricultural, and reclamation projects. Energy development, which requires large amounts of water during extraction, transport, and conversion of resources to a usable form, can potentially result in serious degradation of water quality in the basins.

2. CONCLUSIONS

1. Water availability in the study area will be the major factor limiting future growth and development patterns, including development of energy resources. Surface discharge in both river systems, particularly in the Little Missouri Basin, is highly variable and cannot be relied upon to provide year-round flow for anticipated consumptive use without creation of additional storage facilities. Interbasin transport of water from sources such as the Yellowstone River, as well as expanded use of regional ground-water resources, are mechanisms expected to assume increasing importance in meeting projected industrial demands in the Little Missouri and Belle Fourche River Basins.

2. Water quality throughout the Little Missouri and Belle Fourche River Basins is variable and strongly influenced by episodic high runoff and volumes of ground water found in the base flow of intermittent tributaries. Salinity and suspended sediment concentrations are already a problem in both basins, and a number of trace elements are found in prohibitively high concentrations in the Belle Fourche River below the Homestake Mine in South Dakota. Existing water quality, particularly around the mining activities at Gillette, Wyoming, can be expected to deteriorate further as availability of water is reduced with increasing regional development. The water quality parameters most likely affected by increased activities in the basins are salinity, elemental toxic substances, suspended sediments, and nutrients. Exposed pollutants from surface mines are expected to move primarily in conjunction with local storm events.

3. Irrigation is, and will continue to be, the major consumer of surface water in the Little Missouri and Belle Fourche River Basins. Regional, high salinity levels already restrict the variety of crops grown in the area, and increasing salinity, particularly in conjunction with reductions in flow, could have a major impact on this important user.

4. The Belle Fourche and Little Missouri River Basins will be impacted by a variety of energy resource developments, especially associated with coal strip mining in the Gillette, Wyoming, area. Water borne point source discharge of pollutants from these development sites should be localized and should not pose a problem to overall water quality in the basins if discharge limitations are strictly enforced. Rather, nonpoint pollution from such sources as stack emissions, air borne dust, and subsurface drainage will be the major contributors. Runoff of effluents released from evaporation ponds to ground water or through overflow during storms poses an additional water quality threat, and regular monitoring for potential violations from energy development operation sites should be required.

5. Although point source discharges from traditional energy developments are not likely to pose surface water quality problems, the potential for direct contamination of ground-water supplies from in situ coal conversion activities is substantial. Organic pollutants from this source are of particular concern because of both the lack of available data regarding the nature and quantity of such pollutants and the high costs associated with organic analyses.

6. Secondary development pollution impacts are likely to become a major contributing problem to water quality in the Little Missouri and Belle Fourche River Basins. In particular, increases in TDS and sediment levels from urban runoff, hydrologic modifications, and erosion resulting from construction of additional transportation systems are expected.

7. In addition to the long-term trends, an increased number of pollution "episodes" (spills, etc.) are expected as a result of the increased transport of energy products in the area and the likelihood of flood runoffs from waste disposal, cooling systems, or mining sites. These brief, but massive, events could cause both short- and long-term effects that would be disasterous to both the ecology and the economy of the area.

8. Surface water quality stations presently operated by the U.S. Geological Survey are generally well situated to monitor energy resource development impact. However, they are not maintained regularly enough to permit meaningful data evaluations, nor are a number of water quality parameters collected that are considered necessary for monitoring energy activities in the basins. Twelve USGS sampling stations have been selected throughout the basins examined in this report, as having the highest sampling priority, for energy monitoring efforts. Priorities have also been established for selection of water quality parameters necessary to monitor impacts from energy development in these rivers.

3. RECOMMENDATIONS

1. An expansion in the number of parameters regularly monitored to assess the impact of energy development on surface water quality in the Belle Fourche and Little Missouri River Basins is recommended. In particular, most trace elements and nutrients, which are presently collected only irregularly, should be incorporated into a more standardized sampling program. Pesticides, oils and greases, and organics such as phenols are other parameters that should be made part of a regular, if occasional, monitoring effort. Increased use of biological monitoring as a tool for measurement of long-term water quality trends is recommended.

2. The following U.S. Geological Survey stations are recommended to have the highest sampling priority in the Belle Fourche and Little Missouri River Basins for monitoring energy development impact on surface waters:

Belle Fourche River below Rattlesnake Creek, WY
Donkey Creek near Moorcroft, WY
Belle Fourche River below Moorcroft, WY
Belle Fourche River at WY-SD State line
Belle Fourche River near Sturgis, SD
Belle Fourche River near Elm Springs, SD
Little Missouri River near Alzada, MT
Little Missouri River at Marmarth, ND
Little Missouri River at Medora, ND
Little Missouri River near Watford City, ND

It is recommended that the present surface water monitoring network be restructured. The Little Missouri station at Watford City, North Dakota, and the Belle Fourche station at Elm Springs, South Dakota, should be sampled weekly in order to permit meaningful trend analyses. If resources permit, an additional station on the Belle Fourche River near Moorcroft, Wyoming, should also be sampled weekly. Stations should be added on Whitewood Creek and the Belle Fourche River above Whitewood Creek. These two new sites, as well as the seven other priority stations throughout the study area, should be monitored on a monthly basis to provide spatial distribution data.

3. The following water quality parameters are recommended for sampling at the 12 priority stations to permit an assessment of energy resource development impact in the Belle Fourche and Little Missouri Basins:

Total alkalinity
Total aluminum
Total arsenic
Bicarbonate
Biological oxygen demand of bottom sediments
Total boron
Total cadmium
Total organic carbon in bottom sediments
Dissolved calcium
Chloride
Total chromium
Specific conductance
Total copper
Total cyanide
Flow
Fluoride
Total iron
Total lead
Dissolved magnesium
Total manganese
Total mercury
Total molybdenum
Dissolved oxygen
Total nickel
Nitrate-nitrite-N
Pesticides
Petroleum hydrocarbons
pH
Total phosphorus
Dissolved potassium
Total selenium
Dissolved sodium
Dissolved sulfate
Suspended sediments
Temperature
Total dissolved solids

4. A ground-water monitoring network should be established in the region, particularly around the Gillette, Wyoming, area and at in situ coal conversion and uranium leaching operations just outside the study area boundaries. Sampling of this network should be on a semiannual or quarterly basis.

5. Continued research involving periodic, intense field surveys to determine the nature and extent of pollution discharges from developing coal gasification and conversion sites is recommended, especially for those in situ project areas that will create many potentially harmful organic compounds. The exact nature and degree of escape of these compounds is presently unknown.

6. An inventory of all water right allocations, including average annual consumptive use of surface waters, is recommended for the Little Missouri and Belle Fourche River Basins. Such an inventory would provide comprehensive data for the four States affected by the river drainages and provide a basis for future decisions in water right assignments and construction of additional storage facilities.

7. Establishment of enforceable minimum instream flow requirements in the Belle Fourche and Little Missouri River Basins is recommended in light of the anticipated impact to fisheries and recreational activities during low water years as a result of increasing energy development.

4. STUDY AREA

GEOGRAPHY

Location and Size

The Belle Fourche and Little Missouri River Basins are located along the border region of the States of Montana, Wyoming, North Dakota, and South Dakota (Figure 1). The area examined in this report occupies approximately 40,197 km^2 in 16 counties of the 4 States and is defined by the following points: Pumpkin Buttes near Pine Tree, Wyoming; the confluence of the Belle Fourche with the Cheyenne River, South Dakota; Gustave, South Dakota; where the Little Missouri River enters Lake Sakakawea (Garrison Reservoir), North Dakota; and Watford City, North Dakota.

The Belle Fourche (18,674 km^2) is a largely perennial river, which originates near the Thunder Basin National Grasslands in Campbell County, Wyoming, and flows eastward to its confluence with the Cheyenne River (Briggs and Ficke 1977). The Little Missouri River (21,523 km^2) originates in the northeast corner of Wyoming in Crook County and flows northeastward for 900 stream-km through Montana and the Dakotas to its junction with Lake Sakakawea (Northern Great Plains Resource Program 1974). The entire study area extends approximately 450 km to the north and south and as much as 280 km to the east and west.

Climate

The Belle Fourche and Little Missouri River Basins have a continental, semiarid climate that is characterized by large seasonal and diurnal variations in temperature, with cold winters, hot summers, and low winter precipitation (South Dakota Department of Natural Resources Development 1972; Riis 1977). Riis (1977) states that "although the climate in the Belle Fourche Basin is generally suitable for ranching and growing grain and hay crops, severe temperatures, insufficient precipitation, drought, and blizzards present limitations." General climatic data from several locations throughout the Belle Fourche Basin are presented in Table 2.

Four major air masses and regional topography determine the climate of the study area. Continental polar air masses originate in the north and typically bring dry and cool weather, while the maritime polar air mass that originates in the Pacific Ocean far to the west and north brings cold weather associated with winter snows. Other air masses originate in the Gulf of Mexico and the center of the United States and bring moist, warm spring and dry, warm summer weather (Missouri River Basin Commission 1978a). Frequent weather changes occur with the passage of low pressure systems and their

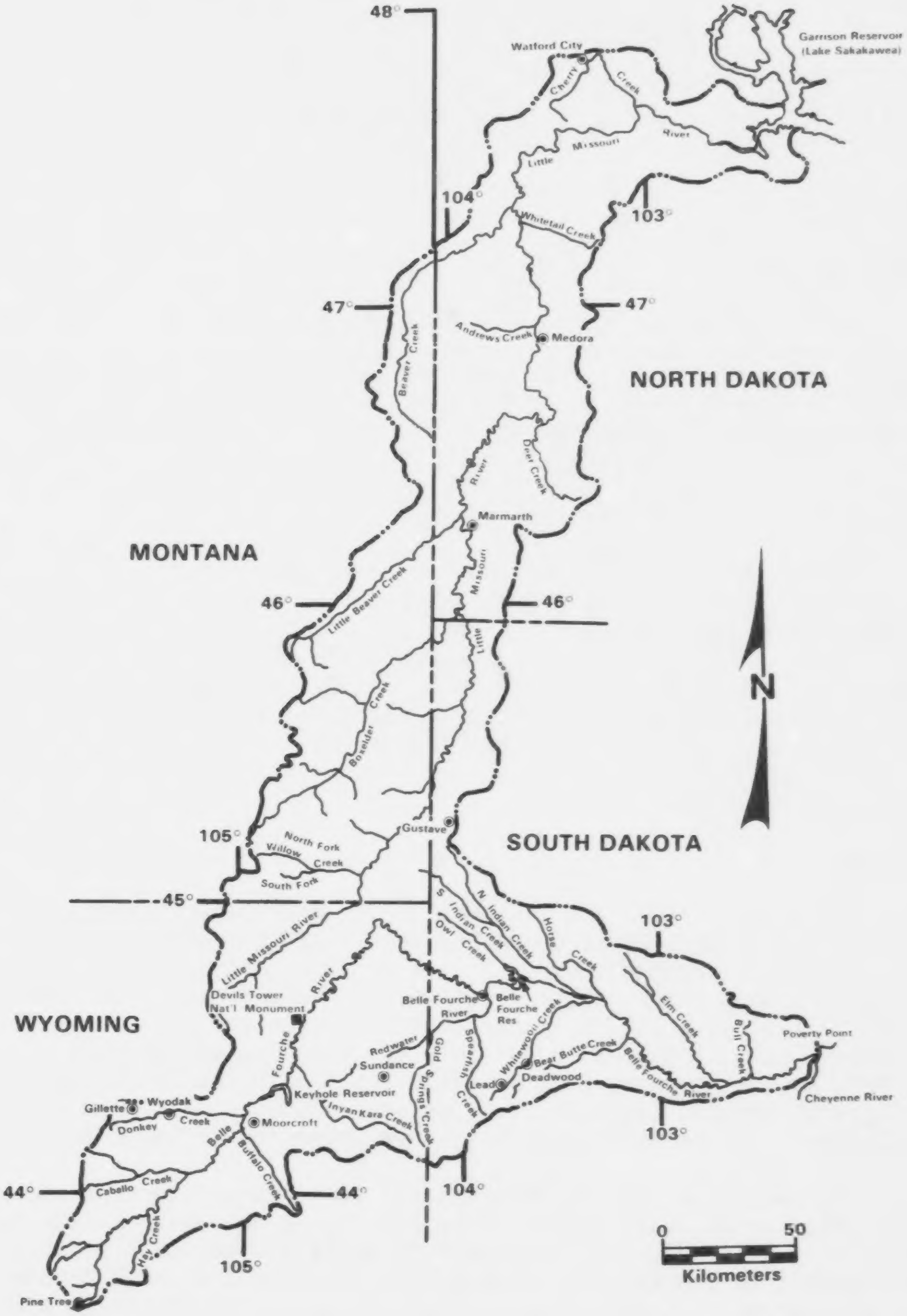

48°
Garrison Reservoir
(Lake Sakakawea)
Watford City
Cherry
Creek
Little
Missouri
River
104°
103°
Whitetail Creek
47°
47°
Andrews Creek
Medora
Beaver Creek
NORTH DAKOTA
River
Deer Creek
Marmarth
Missouri
Little
MONTANA
46°
46°
Little Beaver Creek
N
Boxelder
Creek
Gustave
SOUTH DAKOTA
105°
North Fork
Willow
Creek
South Fork
45°
Little Missouri River
S
Indian Creek
Owl
Creek
N Indian Creek
Horse
Creek
103°
River
Devils Tower
Nat'l Monument
WYOMING
Belle Fourche
River
Belle
Fourche
Res
Elm Creek
Bull Creek
Poverty Point
Whitewood Creek
Bear Butte Creek
Redwater
Sundance
Gold
Springs
Creek
Spearfish
Creek
Lead
Deadwood
Belle Fourche River
Cheyenne River
Fourche
Keyhole Reservoir
Inyan Kara Creek
Gillette
Wyodak
Donkey
Creek
Moorcroft
Belle
Buffalo Creek
103°
104°
44°
44°
Caballo
Creek
Hay Creek
105°
0
50
Kilometers
Pine Tree

Figure 1. Location of the Little Missouri and Belle Fourche River Basins.

TABLE 2. CLIMATIC DATA FOR THE BELLE FOURCHE RIVER BASIN
(Riis 1977, U.S. Geological Survey 1977a)

	Temperature °C				Precipitation	
Station	January Average	July Average	Days 32° or Over	Days -18° or Under	Average Precipitation (cm)	Average Snowfall (cm)
Lead	-5°	20°	6	18	64.5	266.7
Camp Crook	-8°	22°	34	33	34.8	83.8
Newel	-8°	22°	29	27	39.3	53.3
Dupree	-9°	24°	40	33	39.4	93.9
Gillette 2E	-6°	22°	31	20	40.1	144.8

associated cold fronts and thunderstorms. Riis (1977) reports that this frontal activity brings frequent daily and weekly weather changes and is associated with much of the areal annual precipitation.

The average annual precipitation ranges from less than 35.5 cm in the west-southwestern portion of the study area to 40.5 cm and above in the east-central area. The Black Hills area of South Dakota may receive up to 90 cm/yr in some of the higher elevations. Most of the rain received falls during the April-September growing season with June having the highest monthly average (South Dakota Department of Natural Resources Development 1972). In the Belle Fourche Basin near Gillette, much of this rain falls in episodic thunderstorms of short duration and high intensity. These storms often cover only a small area and result in flash floods. Since most water is lost through surface runoff, these storms are of little value to seedling establishment and plant growth in that area (U.S. Geological Survey 1977a). In other portions of the basins, however, high intensity storms causing erosion damage are not a serious problem (South Dakota Department of Natural Resources Development 1972).

Geology

The Little Missouri and Belle Fourche River hydrologic basins originate in the Powder River structural basin, extend east crossing the uplifts of the Black Hills-Miles City arch, and terminate in the Williston structural basin (Figure 2). Sedimentation in the area was controlled by regional tectonic features prior to Late Cretaceous time and recorded the advance and retreat of seas that extended areally over the cratonic basin (Wyoming Geological Association Technical Studies Committee 1965; Carlson and Anderson 1965; Haun and Kent 1965). These seas generally advanced from the north and the west, resulting in thinner sediment layers in the eastern and southeastern portions of the structural basins. Sediment sections over 4,500 m in thickness and representing every geologic period from Cambrian through Tertiary are present in the basin (Carlson and Anderson 1965).

Diastrophic events in Late Cretaceous and early Tertiary times shaped the present-day structural basin and uplifts. During the Paleocene the Black Hills uplift began (Haun and Kent 1965). By Eocene all the major features were delineated, and strong folding and faulting occurred around the Powder River structural basin. The flanking mountains were eroded, and extensive coal swamps formed in the north and central Powder River Basin. These swamps gradually gave way to drier environs to the south and east, and coal beds become thinner and less common in these directions. Basin filling continued with deposition of clays and sands in the Sentinel Butte and unnamed members of the Wasatch Formation (Seager et al. 1942). Renewed uplift in the Black Hills in late Eocene time tilted the Powder River Basin westward and resulted in erosion of much of these beds.

Early Tertiary igneous activity resulted in intrusion of numerous dikes, sills, stocks, and laccolithes. During Oligocene time, sediments from the Black Hills and sediments and volcanic ash from the area to the west buried most of the Black Hills and areas to the east. A major regional uplift occurred at the close of the Pliocene with extensive normal faulting.

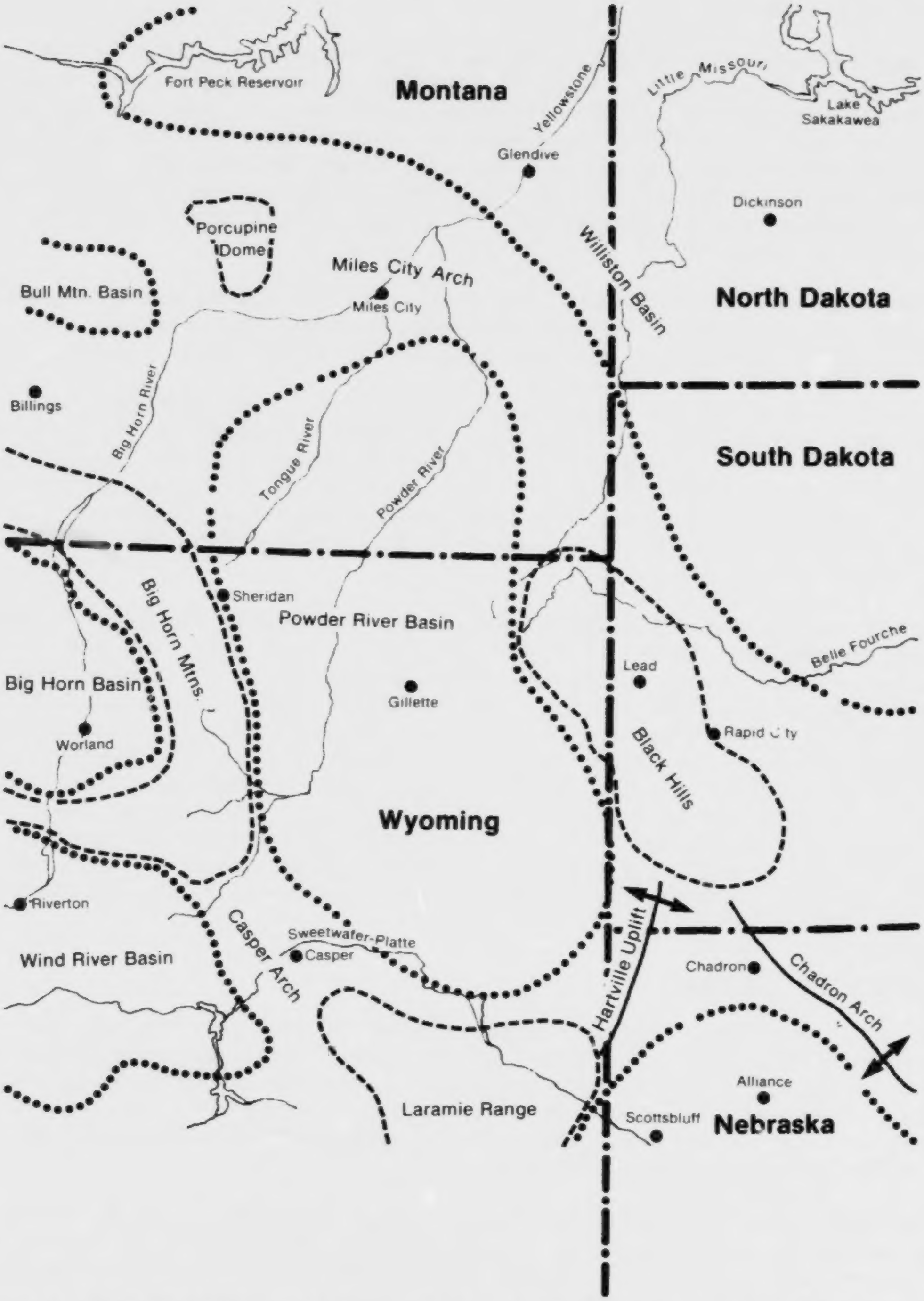

Fort Peck Reservoir
Montana
Yellowstone
Little Missouri
Lake Sakakawea
Glendive
Dickinson
Porcupine Dome
Miles City Arch
Miles City
Williston Basin
North Dakota
Bull Mtn. Basin
Billings
Big Horn River
Tongue River
Powder River
South Dakota
Sheridan
Powder River Basin
Big Horn Mtns.
Belle Fourche
Lead
Big Horn Basin
Gillette
Worland
Rapid City
Black Hills
Wyoming
Riverton
Hartville Uplift
Casper Arch
Sweetwater-Platte
Casper
Wind River Basin
Chadron
Chadron Arch
Alliance
Laramie Range
Scottsbluff
Nebraska

Figure 2. The geologic structure of the Little Missouri and Belle Fourche River Basins.

Erosion accelerated and streams became superimposed across present mountains. Subsequent glaciation and erosion has modified stream courses to their present locations.

A generalized stratigraphic section of the area is presented in Table 3. Surface geology is shown in Figure 3. Commercial coal deposits are found in the Tongue River Member of the Fort Union Formation in Montana and North Dakota, but coal is of minor importance in South Dakota. In the latter area the Ludlow Member is the most prolific coal bearer (Brown 1952). Deposits are also present in the Hell Creek Formation. Petroleum resources have been largely obtained from the Newcastle, Fall River, Lakota, and Minneluska Formations (Gries 1974).

Commercial bentonite deposits are present in the Mowry, Newcastle, and Belle Fourche formations. Mineralized zones in the Black Hills yield precious metals and in the past have been exploited for other minerals.

Geology controls the regional topography. The resistant cap rocks of the Arikaree and White River Formations cap buttes and form cliffs. The soft clays and shales of the Upper Cretaceous and Paleocene form rolling hills and badlands. The uplifted Black Hills with their crystalline cove and steeply sloping, flanking strata result in deep canyons and rugged topography. Devils Tower, a tall butte of columnar rocks, is believed to be the remnant of an intrusive igneous body.

Stream patterns are similarly controlled. Originally the Belle Fourche was part of the present-day Little Missouri River. It was "captured" by a tributary of the Cheyenne, which cut along the strike of soft shales and diverted the Belle Fourche to its present course north of the Black Hills (Darton 1909). The sharp bend in the Little Missouri near its confluence with Lake Sakakawea was caused by glacial diversion. Prior to glaciation, not only the Little Missouri, but the Missouri and Yellowstone Rivers flowed north into Canada and east into Hudson Bay. Advancing ice forced the Missouri to its present course and diverted the Little Missouri sharply eastward. As a result, the river obtained a shorter, steeper course and cut rapidly downward creating the present badlands along its route (Missouri River Basin Commission 1978a).

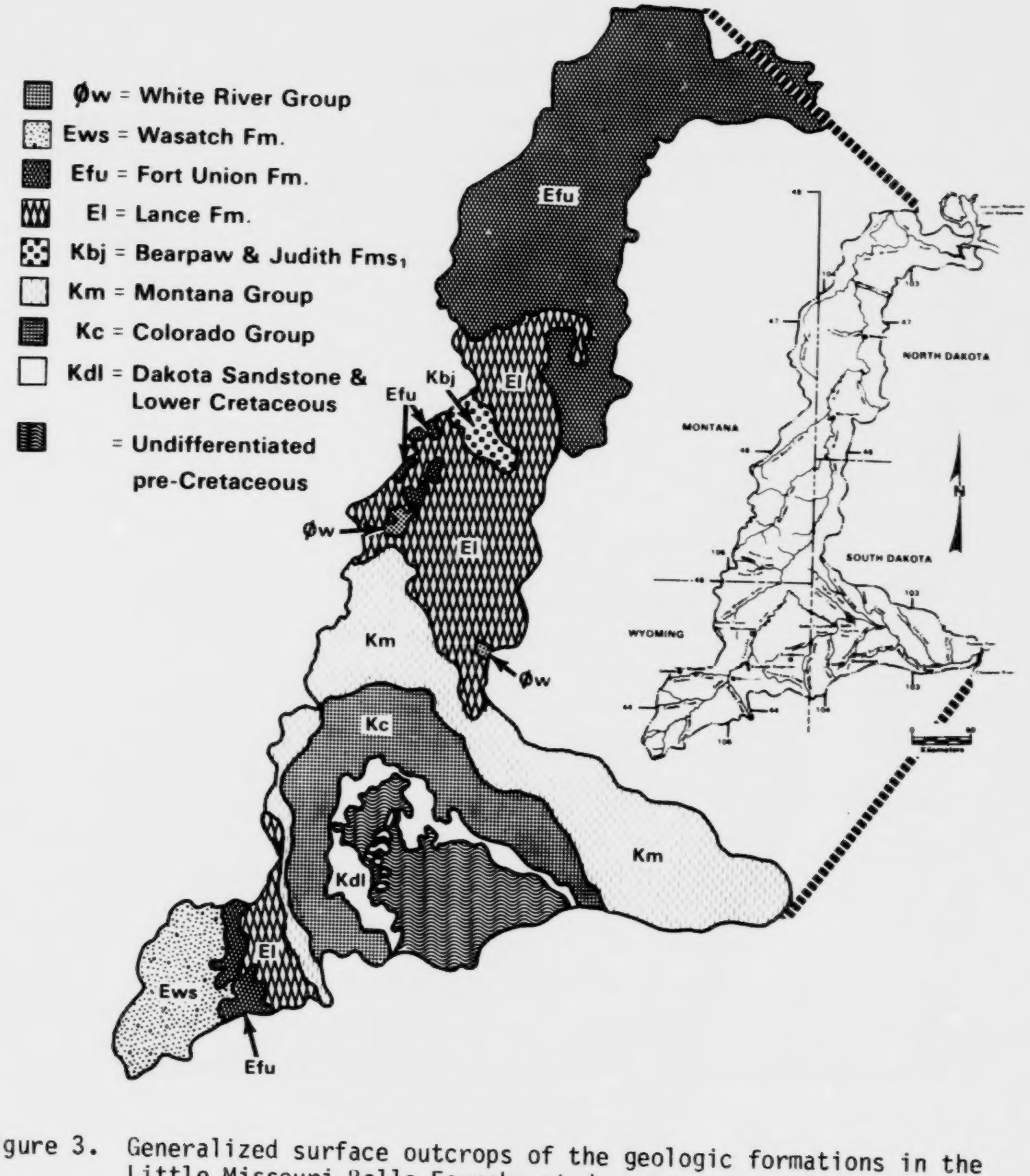
Population and Economy

It is expected that increasing development of the coal industry and accompanying secondary construction of new roads, railroads, powerlines, and centers of industry will bring new growth to existing communities in the Little Missouri and Belle Fourche River Basins. At present, the area is spotted with many small rural communities, supplemented by a few centers of population along the rivers (Table 4).

The population of the Little Missouri River Basin has been declining since the 1940's, and today the once-major towns of Marmarth and Medora have populations well under 1,000 persons (North Dakota State Water Commission 1975a). Potential for new growth is good, however, because of the anticipated energy development to the east near the Knife, Cannonball, Grand, and Heart River Basins. The Belle Fourche River Basin is most densely

TABLE 3. GENERALIZED GEOLOGICAL STRATIGRAPHIC SEQUENCE IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Period	Epoch	Formation/Member	
Quaternary	Recent	Alluvium and stream terraces	
	Pleistocene	Alluvium and glacial debris	
		Unconformity	
Tertiary	Miocene	Arikaree	
	Oligocene	White River Formation	
		Unconformity	
	Eocene	Wasatch Formation	Golden Valley Member Sentinel Butte Member
	Paleocene	Fort Union Formation	Tongue River Member (West) Lebo Shale Tullock (East) Ludlow-Cannonball Member
		Hell Creek (Lance) Formation	
		Fox Hills Sandstone	
Cretaceous	Upper	Lewis Shale	
		Pierre Shale	
		Niobrara Formation	
		Carlile Shale	
		Green Horn Formation	
		Belle Fourche Shale	
		Mowry Shale	
		Newcastle Sandstone	
		Skull Creek Shale	
	Lower	Fall River Formation	
		Unconformity	
		Lakota Formation	
		Morrison Formation	
Jurassic	Upper	Sundance Formation	
		Unconformity	
	Middle	Gypsum Spring Formation	
		Unconformity	
Triassic-Permian		Spearfish Formation	
		Minnekahta Limestone	
Permian		Opeche Formation	
		Unconformity	
Permian-Pennsylvanian		Minneluska Formation	
		Unconformity	
Mississippian		Phasapa Limestone	
		Eaglewood (Guernsey) Limestone	
		Unconformity	
Ordovician		Whitewood Limestone	
		Roughlock Silt	
		Icebox Shale	
		Alladin Sandstone	
		Unconformity	
Cambrian		Deadwood Formation	



Øw = White River Group
Ews = Wasatch Fm.
Efu = Fort Union Fm.
El = Lance Fm.
Kbj = Bearpaw & Judith Fms₁
Km = Montana Group
Kc = Colorado Group
Kdl = Dakota Sandstone & Lower Cretaceous
= Undifferentiated pre-Cretaceous
Efu
Kbj
Efu
El
Øw
El
Km
Øw
Kc
Kdl
Km
El
Ews
Efu
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING
N

Figure 3. Generalized surface outcrops of the geologic formations in the Little Missouri-Belle Fourche study area.

TABLE 4. MAJOR AND MINOR POPULATION CENTERS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS, 1970 CENSUS

Communities	Population
Montana	
Wibaux	644
Alzada	50
Boyes	15
Carlyle	15
North Dakota	
Watford City	1,865
Marmarth	319
Medora	133
Wyoming	
Gillette	12,000†
Sundance	1,056
Moorcroft	981
Hulett	318
Beulah	65
Alva	50
Rozet	25
Aladdin	15
Devils Tower	10
New Haven	10
Oshoto	5
South Dakota	
Lead	5,420
Spearfish	4,661
Sturgis	4,536
Belle Fourche	4,236
Deadwood	2,409
Whitewood	689
Newell	664
Central City	188
Nisland	157
Fruitdale	74

†1974 census data from University of Oklahoma and Radian Corporation (1977a).

populated in South Dakota, where the 1970 census reported a total basin population of 34,437 persons. This represents an areal density of four persons/km^2, which is slightly higher than the State average (Riis 1977). However, 55 percent of this population is contained in the four leading cities -- Belle Fourche, Lead, Spearfish, and Sturgis. The largest city in the Belle Fourche Basin is Gillette, Wyoming, which had doubled its 1960 population by 1974 and may increase to 40,000 by the year 1985 (University of Oklahoma and Radian Corporation 1977a).

There is a tendency in the study area towards movement from rural communities to the cities, reflecting an economic shift from farming to municipal and industrial vocations. Not only is energy development creating industry to draw workers away from the farm, but with the increasing mechanization of agricultural procedures there are fewer farm-related jobs available. Nevertheless, Riis (1977) reports that in the Belle Fourche Basin in South Dakota both rural and urban populations have been increasing at the same rate since 1950.

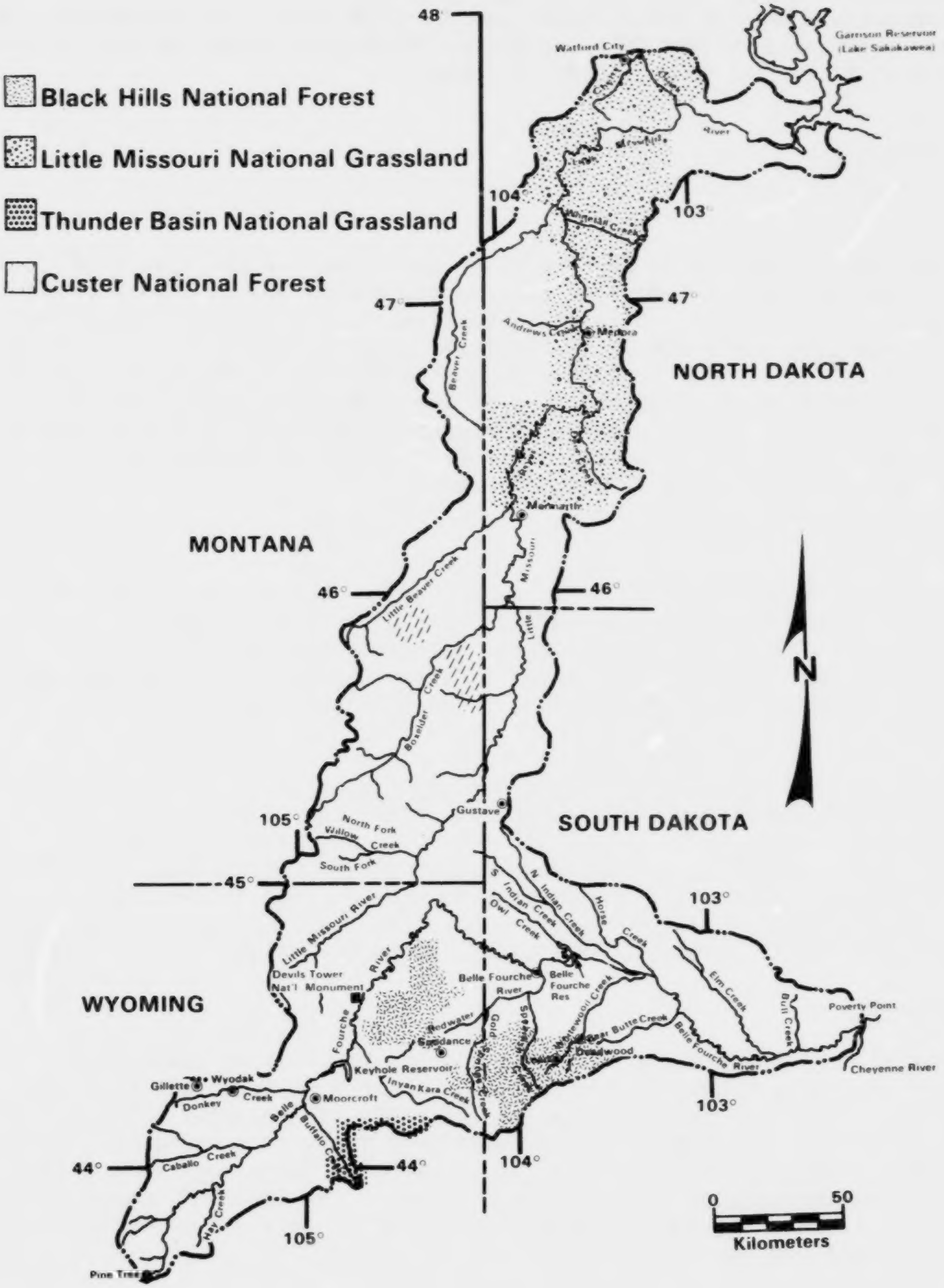
Agriculture is still the primary sector of the economy, with major production of small grains (soybean, flax, rye, and alfalfa) and meat processing ongoing in the basins (Missouri Basin Inter-Agency Committee 1971a). Coal mining activities are also a major economic factor in the Belle Fourche River Basin near Gillette, Wyoming; near Lead, South Dakota, the major source of revenue is the Homestake Gold Mine. It is expected, however, that, even with increasing energy development activities in the vicinity of Gillette and throughout the basins, agriculture will continue to dominate the areal economy for years to come (Missouri River Basin Commission 1978a).

Land Ownership and Usage

The greatest percentage of land in the Little Missouri and Belle Fourche River Basins (approximately 65 percent) is privately or State owned. The remaining basin lands are Federally owned. These Federal lands are administered by the Bureau of Land Management, the U.S. Forest Service, and the National Park Service. Almost all of the Little Missouri River in North Dakota flows through the Little Missouri National Grasslands. Other major Federally controlled lands in the basins include the Thunder Basin National Grasslands, the Black Hills and Custer National Forests, Devils Tower National Monument, and the Belle Fourche, Stewart Lake, and White Lake National Wildlife Refuges (Figure 4).

It is estimated that 85 percent of the land in the Little Missouri and Belle Fourche River Basins is developed for agricultural purposes (Riis 1977). This figure includes rangeland and timberland used for grazing as well as cropland. Most of the cropland in the drainage basins is irrigated land; in northeast Wyoming only 2 percent of the total agricultural use is in dryland crops (Missouri River Basin Commission 1978b). The irrigated farmlands produce primarily wheat, hay, alfalfa, oats, and barley.

Industrial utilization of land, such as mining, and urban development are relatively slight, particularly in light of the economic benefits to the area derived from the exploitation of its mineral resources. In the Little Missouri Basin in South Dakota, only 1 percent of the land is devoted to



Black Hills National Forest
Little Missouri National Grassland
Thunder Basin National Grassland
Custer National Forest
48°
47°
46°
45°
44°
105°
104°
103°
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING
N
Watford City
Garrison Reservoir (Lake Sakakawea)
River
Andrews Creek
Medora
Beaver Creek
Marmarth
Missouri
Little
Little Beaver Creek
Boxelder Creek
Gustave
North Fork
Willow
Creek
South Fork
Little Missouri River
S Indian Creek
N Indian Creek
Owl Creek
Horse Creek
Elm Creek
Bull Creek
Poverty Point
Cheyenne River
Devils Tower Nat'l Monument
Belle Fourche River
Belle Fourche Res
Redwater
Sundance
Whitewood Creek
Bear Butte Creek
Deadwood
Belle Fourche River
Spearfish Creek
Gold Springs Creek
Keyhole Reservoir
Inyan Kara Creek
Fourche River
Gillette
Wyodak
Donkey Creek
Moorcroft
Belle
Buffalo Creek
Caballo Creek
Hay Creek
Pine Tree
0
50
Kilometers

Figure 4. Federal, State, and other land areas in and around the Belle Fourche and Little Missouri River Basins.

urban use (South Dakota Department of Natural Resources Development 1972). Recreation, including fishing, hunting, boating, camping, and general vacation activities, is also a major use of basin land. The estimated area in major land use and ownership categories in the Belle Fourche and Little Missouri River Basins is presented in Table 5.

WATER RESOURCES

Lotic

High flows in the Belle Fourche River are primarily the result of intermittent snowmelt runoff from surrounding buttes and mountains (U.S. Geological Survey 1977a), while elevated flows in the smaller tributaries in the drainage area are a result of localized, high-intensity rain. Most of the precipitation (annual average = 28 cm) in the Little Missouri River Basin is also in the form of rain, and flow in the river fluctuates greatly in response to seasonal thunderstorms (Northern Great Plains Resource Program 1974). Lotic resources in both basins are greatest during the high precipitation months of May, June, and July.

Lentic

There are two major reservoirs in the Little Missouri-Belle Fourche study area, both of which are located in the Belle Fourche River Basin: Keyhole Reservoir (38.02 km^2) and the offstream Belle Fourche Reservoir (32.53 km^2). Other smaller reservoirs exist as resources to aid irrigation and livestock watering needs, but these are substantially smaller in size (Table 6).

There are two natural lakes in the study area. Stewart Lake, east of Marmarth, North Dakota, is located on Deep Creek and stores runoff from nearby buttes. Bear Butte Lake, situated on Spring Creek northeast of Sturgis, stores runoff from the Bear Butte-Oyster Mountain area. The lack of natural lentic resources in the study area coupled with increasing agricultural demands for water have resulted in proposals for construction of several additional storage facilities on the Little Missouri River (Table 7).

Ground Water

Most of the ground water that is available to wells in the Little Missouri and Belle Fourche River Basins is located in bedrock formations (Table 8). This is a result of the great thickness and areal extent of the bedrock aquifers as compared to the relatively thin, unconsolidated aquifers found in the limited flood-plain alluvium (Wyoming State Engineers Office 1972). Nevertheless, aquifers in the unconsolidated material generally yield water at a faster rate and recharge from surface supplies faster than do the unconsolidated bedrock material.

In the Little Missouri River Basin, the ground-water aquifers are the result of glacial drift during the Pleistocene. These drifts have exposed many Cretaceous and early Tertiary rocks, creating a belt extending from

TABLE 5. ESTIMATED AREA IN MAJOR LAND USE CATEGORIES FOR THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS*

			Usage (km^2)			
State	Cropland	Pastures-Range	Woodland	Total Federal	Total State	County, Private Total Municipal
Montana	1675	6394	361	4025	936	3619
Wyoming	763	8371	1000	2626	1052	6828
South Dakota	2056	4511	339	1230	311	6800
North Dakota	4302	5729	162	7414	842	4464

*Modified from South Dakota Department of Natural Resources Development (1972), Wyoming State Engineers Office (1972), North Dakota State Water Commission (1975a), Riis (1977), Missouri River Basin Commission (1978a), and R. Ottenbreit, Montana State Land Office, Billings, Montana, Personal communication (1978).

TABLE 6. EXISTING RESERVOIRS AND LAKES IN THE BELLE FOURCHE-LITTLE MISSOURI STUDY AREA**

Reservoir	River Location	Volume ($m^3 \times 10^6$)
Keyhole	Belle Fourche	234.0
Belle Fourche	Belle Fourche	237.0
Ludlow	Little Missouri	13.6
Bear Butte Lake	Spring Creek	0.8
Camels Butte	Little Missouri	0.9
Odland	Little Missouri	1.3
Palunak	Little Missouri	0.1
Bosserman	Little Missouri	1.2
Spring	Little Missouri	0.2
Bradae	Little Missouri	0.2
ND no name 266	Little Missouri	0.1
ND no name 268	Little Missouri	0.2
Stewart	Deep Creek	0.9
Uekert	Little Missouri	0.1
Williams	Little Missouri	0.2
Davis	Little Missouri	0.2
Stone #2	Bowpile Creek	1.9
Humman	Little Missouri	0.4
Gillette	Stonepile Creek	3.5
Newell	Willow Creek	3.2
Cox	(spring-fed lake)	0.4
Iron Creek	Iron Creek	0.4
Mud	Unnamed creek*	
Mirror	(spring-fed lake)	<0.1
Fort Meade	Unnamed tributary of Spring Creek	
Hereford	Unnamed creek*	
Kellog	Unnamed creek*	

*Belle Fourche River Basin

**Modified from Missouri Basin Inter-Agency Committee (1971a), Missouri River Basin Commission (1978b), North Dakota State Water Commission Commission (1975b), and Riis (1977).

Garrison Reservoir nearly to South Dakota (McGuinness 1963). Those wells situated in North Dakota yield the highest quality water in the basin; however, the ground-water supply in this State is much less plentiful than in other States of the study area. In the Belle Fourche Basin, the majority of the ground water used comes from aquifers below the Pierre Shale. The Minneluska Formation is the primary aquifer providing local ground water for mining operations, powerplants, municipalities, and irrigation (Riis 1977).

Only 3.5 percent of the total ground water available through wells in northeastern Wyoming is consumed annually for beneficial uses (Wyoming State

TABLE 7. PROPOSED RESERVOIRS ON THE LITTLE MISSOURI RIVER (Modified from Northern Great Plains Resource Program 1974)

Reservoir	Storage Capacity (m^3 x 10^6)
Marmarth	621
Medora	409
Wagon Creek	283
Beaver	109
Mill Iron	55

TABLE 8. GROUND-WATER FORMATIONS KNOWN TO OCCUR IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS, NORTHEASTERN WYOMING (Modified from Wyoming State Engineers Office 1972)

Formation	Ground-Water Potential
Alluvium	Yields water to numerous stock and domestic wells and to some irrigation wells. May yield up to 1,300 liters/min.
Fort Union Formation	Numerous stock and domestic wells reportedly yield 8 to 378 liters/min.
Lance Formation	Reportedly yields 4 to 1,800 liters/min.
Parkman Sandstone	Sandstone reportedly yields 15 to 227 liter/min.
Newcastle (Muddy) Sandstone	Yields small amounts of water to wells (in excess of 75 liters/min reported). A very important oil-bearing reservoir rock.
Inyan Kara Group (Formation)	Reported yields range from 4 to 825 liters/min. Many domestic and stock wells use this source. Many wells flow at the surface.
Morrison Formation	Yields water to domestic and stock wells.
Sundance Formation	May yield small amounts of water to wells.
Sundance-Gypsum Spring Formation	Unreported, but probably poor potential.
Spearfish Formation	Yields water to domestic and stock wells.
Minnekahta Limestone	Not normally an aquifer but has yielded highly mineralized water in oil exploration wells.
Minneluska Formation	Reported yields are in the range 19 to 7,600 liters/min. A very important oil-bearing reservoir rock.

Engineers Office 1972). Most of the natural recharge to unconsolidated aquifers in the area provides a base flow for surface streams, recharges consolidated aquifers, or is lost to evaporation. It is estimated that in Wyoming there are 45 million m^3 of ground water in storage available in the Little Missouri Basin and an estimated 168 million m^3 available in the Belle Fourche Basin (Wyoming State Engineers Office 1972).

Ground-water supplies in the study area are used primarily for stock and domestic purposes (Missouri River Basin Commission 1978b). These domestic and stock wells are typically shallow, intermittent producers and yield water of highly mineralized quality (Wyoming State Engineers Office 1972).

Approximately 51 percent of the municipal needs in northeastern Wyoming are satisfied by ground-water resources (Wyoming State Engineers Office 1972). This fraction may soon increase with the expanded use of brackish water as a source of municipal and industrial water. The city of Gillette is building a desalinization plant that will treat water from the Wasatch Formation and reduce TDS content by more than half. This previously unutilized water supply will supplement higher quality ground-water resources presently being used, especially during peak water demand periods (Wyoming State Engineers Office 1972).

Comparatively little ground water is utilized for irrigation purposes in the study area. In Wyoming, ground water is the primary source used for irrigation of approximately 4.3 km^2 in the Belle Fourche River Basin and 1.5 km^2 in the Little Missouri Basin (Wyoming State Engineers Office 1972). An additional 2.0 km^2 in the Wyoming portion of the Belle Fourche Basin are irrigated using ground water as a supplemental source. These irrigation demands deplete approximately 0.8 million m^3 of ground water in the Little Missouri and 2.0 million m^3 in the Belle Fourche Basin every year. Although the number of acres being irrigated with ground-water supplies is expected to stay constant, future irrigation-related consumptive demands on ground water may increase as a result of the need to flush soils in the area presently being irrigated with water having high sodium and salinity hazards (Wyoming State Engineers Office 1972).

Industrial users, particularly the petroleum and coal industries, are expected to use increasing quantities of ground water. An increase in ground-water use is also anticipated for the uranium industry (Wyoming State Engineers Office 1972). There are only a few ground-water aquifers capable of satisfying long-term industrial needs with a continuous water supply in the study basins, including sandstone of the Fox Hills, Inyan Kara, and the Minneluska groups. Furthermore, withdrawals of ground water from these sources for industrial use would likely be in competition with many existing stock and other user wells.

WATER USES

The surface water resources in the arid Little Missouri and Belle Fourche watersheds serve a variety of needs. Streams in the basins, as well as Keyhole Reservoir, provide water for such uses as municipal water supplies, irrigation, recreational activities (including fishing and other sports), industrial needs, livestock watering, governmental uses (fisheries and State water), and limited generation of electricity (Table 9).

FISH AND WILDLIFE RESOURCES

The Belle Fourche and Little Missouri River Basins support a variety of fish and wildlife. In the Little Missouri, fishery investigations have revealed a striking change in species composition over the past 80 years. The major factors that have produced this change are increased silt load, increased peak flows, the creation of Garrison Reservoir, and a decrease in the length of flow periods (Northern Great Plains Resource Program 1974).

Presently, walleye, sauger, and northern pike are the most popular game fish in the Little Missouri Basin. Small reservoirs along the Little Missouri, where larger perennial bodies of water occur, also support such species as catfish, white bass, paddlefish, and crappie (Table 10). Flathead chub, sturgeon chub, and northern plains minnow are also found during periods of seasonal flow (Northern Great Plains Resource Program 1974). Occasionally largemouth bass, yellow perch, bluegill, and bullhead are collected.

Since many of the streams in the Belle Fourche River drainage are intermittent or have low flows and high water temperature, the fishery of that basin is extremely limited. Nongame species dominate the fish population in the river, although channel catfish, walleye, bullhead, and green sunfish can be found in localized perennial pools throughout the basin or in the mainstem below Keyhole Reservoir. A few of the tributaries in the Belle Fourche Basin, such as Spearfish Creek, support healthy trout populations (Riis 1977). Both rainbow and brook trout were introduced into the Black Hills in the 1800's, but since that time general habitat conditions in the streams have deteriorated causing adverse effects on natural reproduction and carrying capacity. Streams now have to be stocked with catchable-size trout to keep up with fishing demands (Missouri Basin Inter-Agency Committee 1969a).

Wildlife in the Northern Great Plains includes a host of game animals such as deer, antelope, prairie grouse, pheasant, and various water fowl. Near the Cordero Mine in Campbell County, Wyoming, antelope, mule deer, bobcats, coyotes, raccoons, weasels, mink, badgers, and skunks are common (U.S. Geological Survey 1975b). The avian population near Cordero includes the sage grouse, Hungarian partridge, chukar partridge, golden eagle, bald eagle, marsh hawks, red-tailed hawks, horned larks, western meadowlarks, buntings, and Brewer's sparrows (U.S. Geological Survey 1975b). North and South Dakota now contain the largest sharp-tailed grouse populations remaining anywhere (Missouri Basin Inter-Agency Committee 1969a).

In the higher elevations of the Black Hills, which reflect a characteristic pondorosa pine community, populations of white-tailed deer predominate. Elk are also present, but populations are small and limited to the Black Hills area (Missouri Basin Inter-Agency Committee 1969a).

Many types of waterfowl are associated with the riparian habitat. Some of these include mallards, teals, gadwalls, shovelers, and widgeon. These

TABLE 9. PERCENTAGE OF TOTAL WATER WITHDRAWALS AND WATER CONSUMED IN THE LITTLE MISSOURI-BELLE FOURCHE RIVER STUDY AREA THAT ARE ASSOCIATED WITH VARIOUS BENEFICIAL USES, 1965 (Modified from Water Resources Council 1968)

River Basin	Domestic	Municipal	Industrial	Livestock	Agriculture	Steam Electric Power
Water Withdrawn						
Belle Fourche	1	4	5	8	82	0
Little Missouri	4	14	4	22	47	9
Water Consumed						
Belle Fourche	2	2	4	13	79	0
Little Missouri	7	6	2	35	49	1

TABLE 10. FISH SPECIES KNOWN TO OCCUR IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS*

Common Name	Scientific Name**
Shovelnose sturgeon	Scaphirhynchus platorynchus
Paddlefish	Polyodon spathula
Goldeye	Hiodon alosoides
Rainbow trout	Salmo gairdneri
Brown trout	Salmo trutta
Northern pike	Esox lucius
Carp	Cyprinus carpio
Brassy minnow	Hybognathus hankinsoni
Silvery minnow	Hybognathus nuchalis
Plains minnow	Hybognathus placitus
Sturgeon chub	Hybopsis gelida
Flathead chub	Hybopsis gracilis
Golden shiner	Notemigonus crysoleucas
Emerald shiner	Notropis atherinoides
Sand shiner	Notropis stramineus
Fathead minnow	Pimephales promelas
Longnose dace	Rhinichthys cataractae
Creek chub	Semotilus atromaculatus
River carpsucker	Carpiodes carpio
Longnose sucker	Catostomus catostomus
White sucker	Catostomus commersoni
Blue sucker	Cycleptus elongatus
Shorthead redhorse	Moxostoma macrolepidotum
Black bullhead	Ictalurus melas
Channel catfish	Ictalurus punctatus
Stonecat	Noturus flavus
Flathead catfish	Pylodictis olivaris
Burbot	Lota lota
Brook stickleback	Culaea inconstans
White bass	Morone chrysops
Green sunfish	Lepomis cyanellus
Pumpkinseed	Lepomis gibbosus
Bluegill	Lepomis macrochirus
Smallmouth bass	Micropterus dolomieui
Largemouth bass	Micropterus salmoides
White crappie	Pomoxis annularis
Black crappie	Pomoxis nigromaculatus
Yellow perch	Perca flavescens
Sauger	Stizostedion canadense
Walleye	Stizostedion vitreum vitreum

*Modified from Northern Great Plains Resource Program (1974).
**Common and scientific names of fishes are from Bailey et al. (1970).

migratory birds are a renewable natural resource and also provide a form of recreation. Many lesser sandhill cranes also seasonally travel through the area and, along with the other migrators, are protected by the Migratory Bird Conservation Act and Migratory Bird Hunting Stamp Act.

A few wildlife species in the Belle Fourche-Little Missouri study area are rare or declining and without proper wildlife management may be lost from the area. The black-footed ferret and the peregrine falcon are classified as endangered species, and their populations are being carefully monitored.

The pronghorn antelope is found in all four of the basin States and is a very popular big-game animal. It has recently decreased in numbers as a result of land conversion programs such as sheep fencing, intensive grazing, and cultivated crop production (Missouri Basin Inter-Agency Committee 1969a).

MINERAL RESOURCES

The Belle Fourche-Little Missouri study area has abundant reserves of mineral resources. These resources may be grouped into three categories: the metallics, the nonmetallics, and the fuels (Table 11). The metallics are generally associated with mountainous areas and their peripheral drainage. The nonmetallics and fuel resources are usually located on the plains and rolling hillsides (Missouri River Basin Commission 1978a).

TABLE 11. TYPES OF MINERAL RESOURCES IN THE BELLE FOURCHE-LITTLE MISSOURI RIVER BASINS STUDY AREA (Modified from Missouri River Basin Commission 1978a)

Metallics	Nonmetallics	Fuels
Gold	Fertilizers, phosphates	Crude oil
Silver	Potash	Coal
Copper	Gypsum	Natural gas
Lead	Fluorspar	Petroleum
Zinc	Lime	
Molybdenum	Mica	
Taconite	Salt	
Tungsten	Bentonite clays	
Beryllium	Sand, gravel	
Vanadium		
Chromium		
Uranium		
Lithium		

In general, the most prominent and economically important mineral resources in the area include subbituminous and lignitic coal, natural gas, and petroleum (North Dakota State Water Commission 1975a). In northeast

Wyoming, petroleum accounts for 78 percent of the total revenue from mineral production, with bentonite, coal, and uranium combined accounting for 13 percent of the total revenue production, gas accounting for 3 percent, and natural gas liquid accounting for 5 percent of the total production (Missouri River Basin Commission 1978b).

In the Belle Fourche Basin, mining is the major source of revenue. The Gillette area has the greatest concentration of strippable coal-fields likely to be developed in the Little Missouri-Belle Fourche study region. The mining industry in the Belle Fourche Basin in South Dakota is not coal oriented. Here, the major minerals developed are metallics, which are located almost entirely in the Black Hills region (Table 12, Figure 5),

TABLE 12. MINERAL RESOURCES OTHER THAN COAL LOCATED IN THE BLACK HILLS AREA OF WYOMING AND SOUTH DAKOTA (Modified from Gries 1974)

District, Area, or Mine	Mineral	State*
Lead	Gold and silver	South Dakota (1)
Deadwood-Two Bit	Gold and silver	South Dakota (2)
Garden	Gold and silver	South Dakota (3)
Bald Mountain	Gold and silver	South Dakota (4)
Squaw Creek	Gold and silver	South Dakota (5)
Ragged Top	Gold and silver	South Dakota (6)
Cloverleaf	Gold and silver	South Dakota (7)
Carlile	Uranium	Wyoming (8)
Barlow Canyon	Uranium	Wyoming (9)
Hulett Creek	Uranium	Wyoming (10)
Elkhorn Creek	Uranium	Wyoming (11)
Aladdin	Uranium	Wyoming (12)
Two Bit Gulch	Iron	South Dakota (13)
Strawberry Ridge	Iron	South Dakota (14)
Carbonate	Lead and zinc	South Dakota (15)
Galena	Lead and zinc	South Dakota (16)
Spruce Gulch	Lead and zinc	South Dakota (17)
Clay and shale pits used for brick, bentonite		South Dakota (18)
Pegmatite mining area		South Dakota (19)
Sundance	Gypsum	Wyoming (20)
Spearfish	Gypsum	South Dakota (21)
Sturgis	Gypsum	South Dakota (22)

*Numbers in parentheses indicate specific mineral deposits shown on Figure 5.

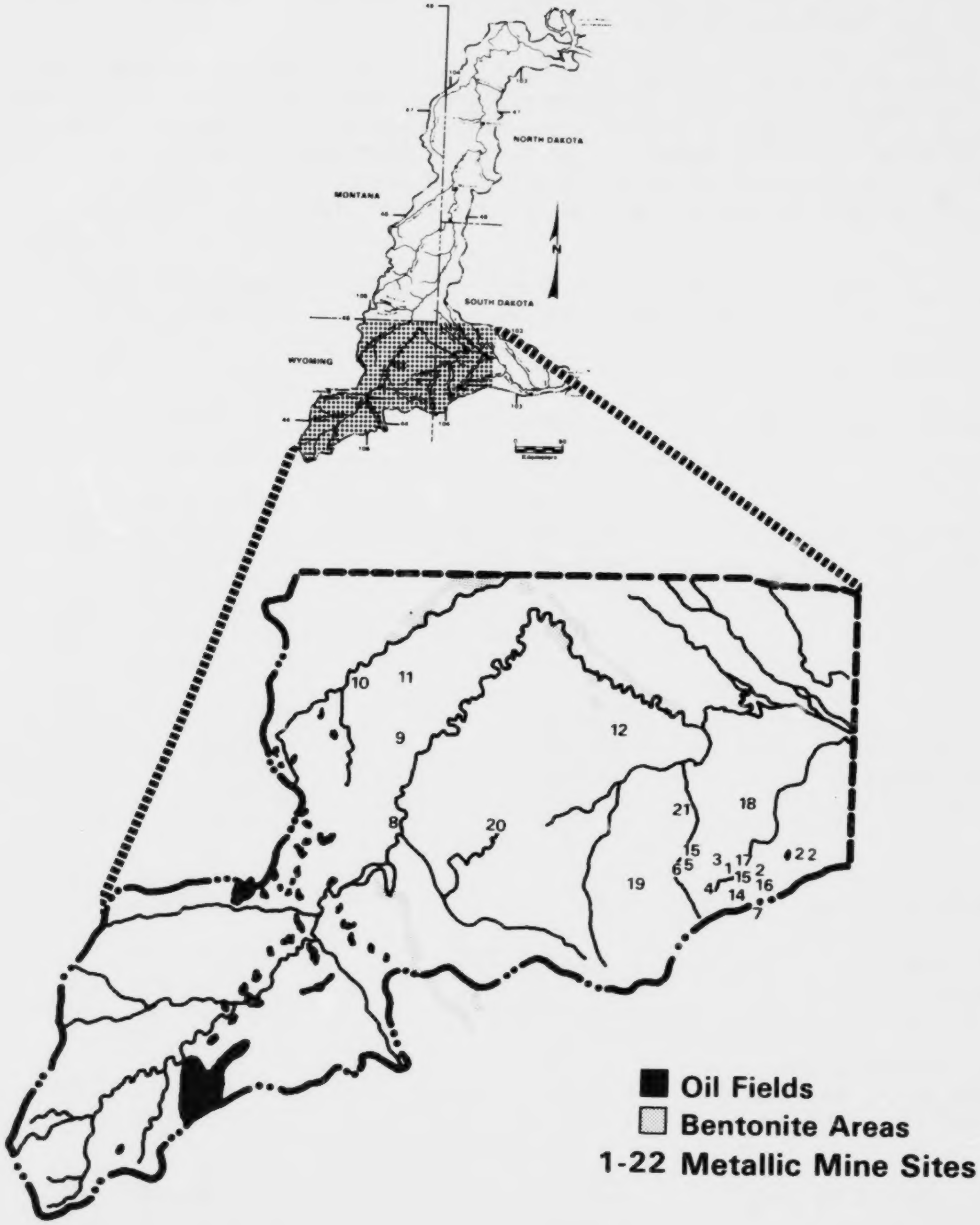

N
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING
104
103
106
10
11
9
12
21
18
8
20
15
6
5
3
1
17
2
22
19
4
15
16
14
7
■ Oil Fields
▨ Bentonite Areas
1-22 Metallic Mine Sites

Figure 5. Map of mineral resources in the Black Hills area of Wyoming and South Dakota.

particularly around the Lead-Deadwood area where gold is produced in the Homestake Gold Mine (Riis 1977). Other mineral resources in the basin include uranium, which is found in the Pumpkin Buttes Uranium District at the headwaters of the Belle Fourche River in Wyoming, and bentonite, which is the most abundant nonenergy mineral commodity in the study area (Missouri River Basin Commission 1978b).

Mineral production in the Little Missouri River Basin is more limited and generally restricted to the mining of nonmetallics such as sand and gravel. There have been a number of oil test wells drilled in this basin in South Dakota, and some thin beds of lignite coal do exist here, but at present there is no commercial potential for the development of either resource (South Dakota Department of Natural Resources Development 1972).

5. ENERGY RESOURCE DEVELOPMENT

ACTIVE DEVELOPMENT

Oil and Gas

The Belle Fourche-Little Missouri study area has outstanding potential for development of oil and natural gas resources. The Nesson anticline, the largest single oil-producing geologic structure in North Dakota, extends northward from the Little Missouri River Basin in northern Dunn County to Lake Sakakawea (Missouri River Basin Commission 1978a). There are numerous producing wells situated throughout this geologic structure. Other areas of retrievable oil include deposits in the bench and bar sands near Dickenson, North Dakota, which extend west to the Little Missouri River (Figure 6). The Amerada Petroleum Corporation in 1953 became the first company producing oil from these latter deposits in North Dakota with the establishment of a well located within the city limits of Fryburg (North Dakota State Water Commission 1975b). Total annual oil production in those North Dakota counties through which the Little Missouri River flows was 23.4 billion liters in 1976 (Table 13).

TABLE 13. TOTAL OIL PRODUCTION FOR COUNTIES IN THE LITTLE MISSOURI RIVER BASIN, NORTH DAKOTA, 1976 (Modified from Missouri River Basin Commission 1978a)

County	Total Production (liters)
Billings	4.2 billion
Bowman	2.2 billion
Dunn	64.9 million
Golden Valley	67.7 million
McKenzie	16.7 billion
Slope	142.3 million

In the Wyoming portion of the study area, the most significant oil production is from the Hilight Oil Field in the Belle Fourche River Basin in Campbell County. Production in this field in 1970 totalled 2.0 billion liters of oil and 445 thousand m^3 of gas and in the entire State was second

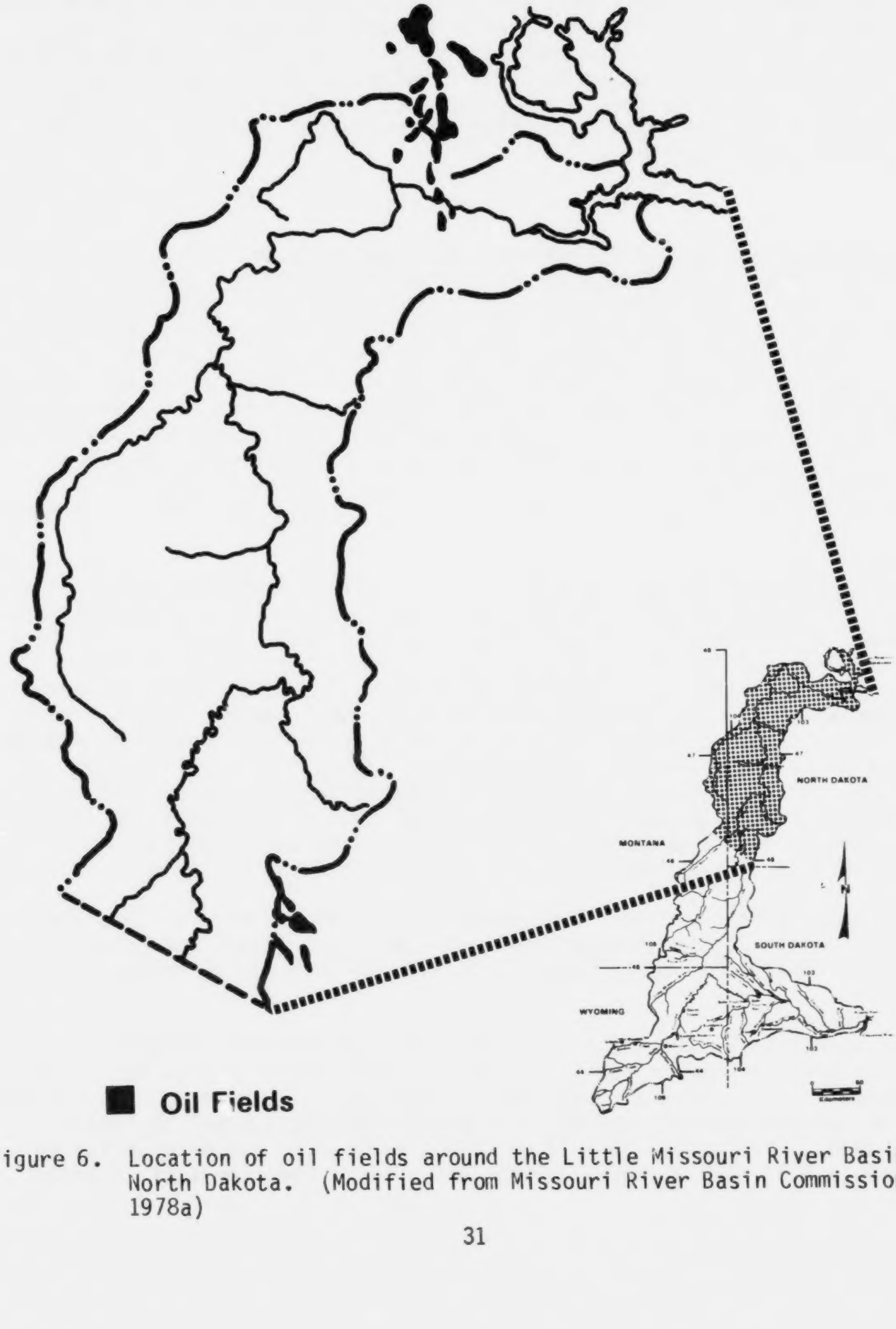

■ Oil Fields
NORTH DAKOTA
MONTANA
SOUTH DAKOTA
WYOMING
N

Figure 6. Location of oil fields around the Little Missouri River Basin, North Dakota. (Modified from Missouri River Basin Commission 1978a)

in production only to the Salt Creek Field in the Powder River Basin (Wyoming State Engineers Office 1972).

The amount of water required for the production of natural gas is negligible. In the production of crude oil, however, substantial volumes of water are required to inject into the petroleum reservoirs and displace oil into producing oil wells (Wyoming State Engineers Office 1972). It was estimated by the Wyoming State Engineers Office (1972) that, between 1972 and 1982, 46.2 million m^3 of water would be required by the Hilight Field for this purpose. Investigations are ongoing into the feasibility of using wells from the Fox Hills and shallow sandstone ground-water aquifers to provide these needed water supplies.

Coal

Substantial amounts of fossil fuels must be extracted in the near future in order for the United States to satisfy increasing energy demands and to achieve energy self-sufficiency. Coal, 1,000 kg of which is equivalent to the heating value of 788 liters of oil, is the most likely candidate to be used to offset shortages in domestic gas and liquid fuel production. Already coal is gaining in importance in the generation of western electrical power; in the Little Missouri and Belle Fourche River Basins, this valuable resource is found in abundance. It is estimated that eastern Montana and Wyoming and western North and South Dakota have close to 31 trillion kg of combined strippable coal reserves, 17 trillion of which are considered economically recoverable (U.S. Bureau of Reclamation 1972). A good portion of this may be found in the study area.

The majority of the coal resources of the United States (72 percent) are found in the Rocky Mountain and Northern Great Plains States (Atwood 1975). This coal is particularly attractive because 43 percent is located in thick seams (2-40 m) and is close enough to the surface to strip mine (Atwood 1975). Sulfur content is generally low, ranging from 0.2 to 2.0 percent with most samples containing less than 1.0 percent. Heat content ranges from 19 to 22 thousand joules/gm for the Wyoming subbituminous "C" coal, while North Dakota lignites range from 15 to 19 thousand joules/gm (U.S. Bureau of Reclamation 1972). Over 79 percent of the Wyoming coal presently mined is used for electrical generation of power; coal conversion plants (gasification and liquefaction) are proposed for the Wyoming area but potential may be limited because of the restricted availability of water resources.

Several mining operations are currently on line and several more are proposed for the Little Missouri-Belle Fourche study area. Locations of these mines (Figure 7) and a brief discussion on each follow below.

Wyodak Mine--

The Wyodak Mine, located 8 kilometers east of Gillette, Wyoming (Figure 7), began strip mining in 1925. The mine is operated by Wyodak Resources Development Corporation, a subsidiary of Black Hills Power and Light Company. It is 90 percent Federally owned on 4 leases covering 7.8 km^2 of land (Glass 1976). Production in 1974 was 659.4 million kg and is expected to increase to 4.53 billion kg/yr in the 1980's (U.S. Department of Interior 1974).

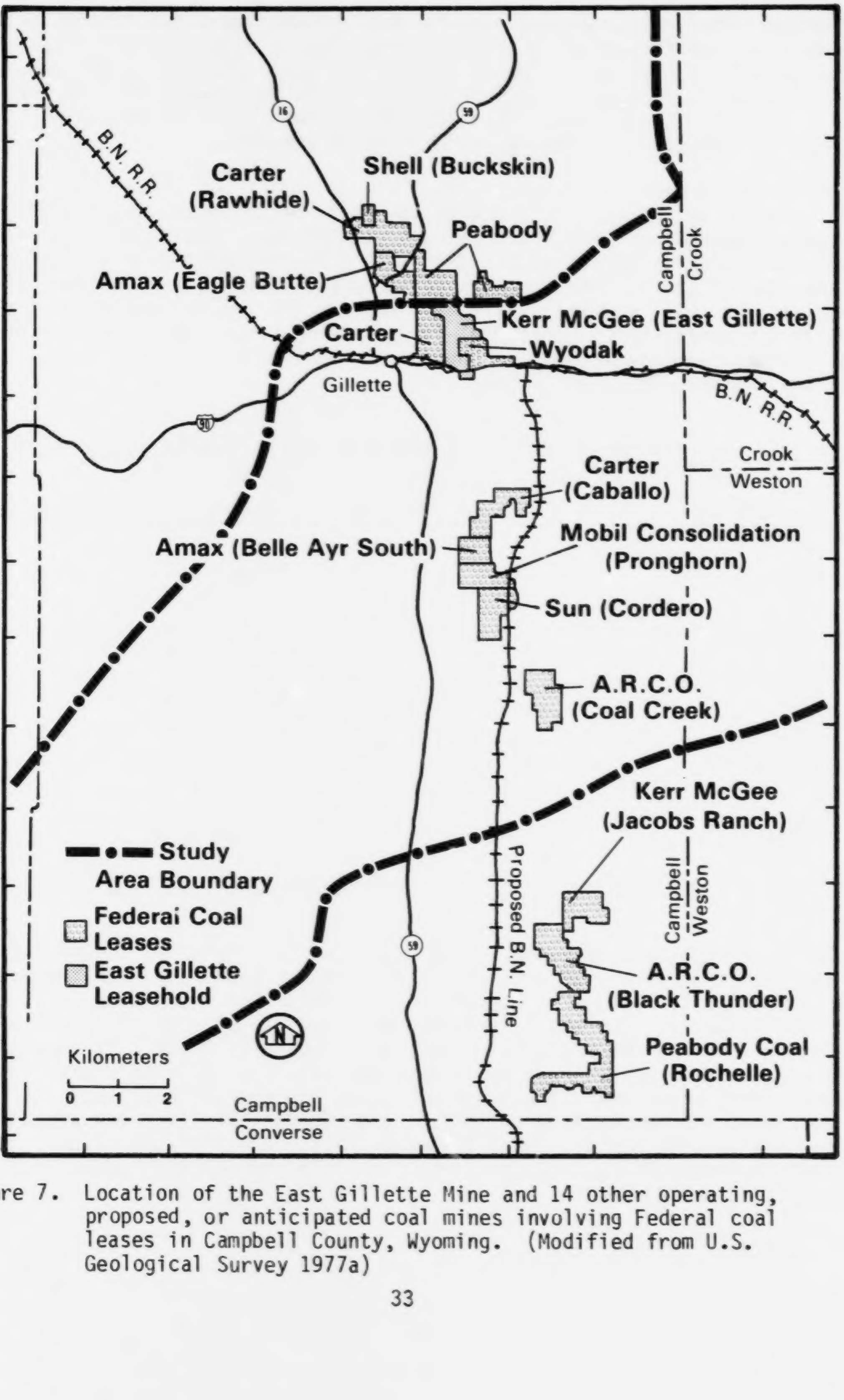

Carter (Rawhide)
Shell (Buckskin)
Peabody
Amax (Eagle Butte)
Kerr McGee (East Gillette)
Carter
Wyodak
Gillette
B.N. R.R.
B.N. R.R.
Campbell
Crook
Crook
Weston
Carter (Caballo)
Mobil Consolidation (Pronghorn)
Amax (Belle Ayr South)
Sun (Cordero)
A.R.C.O. (Coal Creek)
Kerr McGee (Jacobs Ranch)
A.R.C.O. (Black Thunder)
Peabody Coal (Rochelle)
Proposed B.N. Line
Campbell
Weston
Campbell
Converse
16
59
59
90
Study Area Boundary
Federai Coal Leases
East Gillette Leasehold
Kilometers
0 1 2
N

Figure 7. Location of the East Gillette Mine and 14 other operating, proposed, or anticipated coal mines involving Federal coal leases in Campbell County, Wyoming. (Modified from U.S. Geological Survey 1977a)

Ground-water resources are used to meet consumptive water demands of the Wyodak Mine. It is estimated that the mine diverts approximately 1,135 m^3/day of water, one-half of which is used for dust suppression and one-half of which is discharged to Donkey Creek (U.S. Department of Interior 1974). As mining operations increase, water demands will be met by increasing seepage of ground water into mining chambers.

Belle Ayr South Mine--

The Belle Ayr Mine, located 24 km southeast of Gillette, Wyoming (Figure 7), began operation in 1973 and proposes to mine more than 30 billion kg of coal over a 25-year period (Table 14). The mine is composed of several Federal leases and is owned by Amax Coal Company. During the 25-year life of the mine, Amax will strip 11.7 km^2 of land from the Wyodak coalbed at the rate of 0.5 km^2/yr (U.S. Geological Survey 1975a). Coal from the mine has been committed to powerplants throughout the States of Colorado, Texas, Arkansas, Kansas, Ohio, and Iowa.

TABLE 14. MINING PLAN FOR THE BELLE AYR MINE, BELLE FOURCHE RIVER BASIN (Modified from U.S. Geological Survey 1975a)

Year	Production (million kg/yr)
1973	813
1974	3,004
1975	4,535
1976	7,256
1977-96	13,605
1997	12,698
Total	41,911

The Amax Coal Company has diverted 1.2 km of Caballo Creek around the perimeter of the mining area to avoid inflow of surface waters to the open mining pits (U.S. Geological Survey 1975a). This diversion, along with the addition of several storage facilities, will help to control the quality of the water entering the Belle Fourche River via Caballo Creek. At some point during the mining operations, water from Caballo Creek will be routed into a created lake, which will be stocked with fish for recreational use. Ground-water discharges from the mining area during 1974 averaged about 567.7 m^3/day but in 1975 had decreased to approximately 378.5 m^3/day (U.S. Geological Survey 1975a). Approximately 302.8 m^3/day of this water is used for dust control purposes.

Cordero Mine--

The Cordero Mine is located 25 km southeast of Gillette, Wyoming (Figure 7), and is owned and operated by the Sunoco Energy Development Company. Mining began in July of 1976, and by December some 900 million kg of coal had been exposed (U.S. Geological Survey 1975b). Current production is set at 11 billion kg/yr, but Sunoco has already applied for leases that would enable them to double annual production.

Based on present production levels, mining activities are destroying 0.09 km^2/yr of land and by 1981 will increase to disruption of 0.55 km^2/yr. At that point mining will then equal reclamation until the end of the 30-year life of the mine. Coal mined at the Cordero facility will be sent by train to San Antonio, Texas, and to the Laramie River stations of the Missouri Basin Power Project in Wyoming (U.S. Geological Survey 1975b).

Ground-water aquifers in the Cordero Mine occur in the center of the coal-bed so infiltrating water must be regularly pumped out of the pit. This water is used for dust control or stored in two settling ponds that are continuously monitored for water quality. Prevention of surface water runoff from the mine is controlled by diversion ditches, the largest of which is a channel constructed to reduce the number of oxbow loops in the Belle Fourche River (U.S. Geological Survey 1975b). Domestic water used by the mine is obtained from separate wells and stored; sewage generated by the operations is not released to the Belle Fourche River but instead is transported to a package treatment plant.

The Cordero Mine lease area has six producing oil wells on site. Mining activities will avoid these wells, if possible, or temporarily cap them for later use (U.S. Geological Survey 1975b).

East Gillette Mine--

The East Gillette Mine will be operated by the Kerr-McGee Corporation, which holds three Federal coal leases totalling 17.57 km^2 of land. Of this leased area, 58 percent is owned by Kerr-McGee, 12 percent is owned by the State of Wyoming, and 24 percent is owned by private companies or individuals (U.S. Geological Survey 1977a).

The mine is located in Campbell County, Wyoming, about 6.5 km east of Gillette and is adjacent to the Wyodak Coal Mine and Powerplant (Figure 7). Over the 35-year life of the mine beginning in 1979, approximately 487 million m^3 of overburden will be relocated, and approximately 299 billion to 310 billion kg of coal, or 90 percent of the total reserves, will be mined (U.S. Geological Survey 1977a). During mining, 10.8 km^2 of the leased land (0.4 km^2/yr) will be disturbed. This lease area is presently used primarily for grazing and cropland but also holds seven producing oil wells (U.S. Geological Survey 1977a). It is expected that during the mine operation these wells will not be disturbed, but should capping become necessary, they will be reopened after mining activities are completed.

It is estimated that total water consumption of the East Gillette Mine will equal 260 thousand m^3/yr. Most of this water will be used for dust suppression on active haul routes, although approximately 397 m^3/yr will be required for drinking water when the mine is at full production. Sources for the industrially used water will be the surrounding mine drainage, ground-water wells, and possibly the on-site sewage treatment plant (U.S. Geological Survey 1977a). Approximately 72 percent of the drainage from the East Gillette Mine itself will be internal. Only 6 percent of the remainder will drain to Donkey Creek, and 22 percent will flow to Dry Creek in the Little Powder River watershed.

Coal Creek Mine--

A leasehold of 27.2 km^2 of combined Federal, State, and private ownership is proposed for the Coal Creek strip mine (U.S. Geological Survey 1977a). The mine is situated just south of the Cordero Mine and Belle Fourche River in Campbell County, Wyoming (Figure 7). Atlantic Richfield Company plans to begin production at the mine in 1982 with 7.2 billion kg/yr of coal (Missouri River Basin Commission 1978b) and increase to an annual average of 9.1 billion kg/yr later in the 1980's (U.S. Geological Survey 1977a). Total reserves on the leasehold are estimated to equal 310 billion kg of coal (U.S. Geological Survey 1977a). The draft environmental statement for this mine is in production now and will outline the requirements and impacts that are expected from its operation.

Caballo Mine--

The Caballo Mine is currently proposed to go under construction in January 1979. The mine will be located 15 km southeast of Gillette, Wyoming (Figure 7), and is part of the Smith-Wyodak coal seam. It will be operated by the Carter Mining Company under one State lease of 13.5 km^2 and two Federal leases totalling 21.7 km^2 of land. It is projected the mine will produce 430 billion kg of coal over 40 years at an annual rate of 11 billion kg/yr (B. Auffill, Carter Mining Company, Gillette, Wyoming, Personal communication, 1978). The total quantity of land disturbed or the annual anticipated consumptive use of water is not yet available but should soon be forthcoming in the draft environmental statement.

Pronghorn Mine--

The Pronghorn Mine is located 25.6 km southeast of Gillette immediately south of Belle Ayr South Mine (Figure 7). The Consolidation Coal Company is in joint ownership of the mine with the Mobil Oil Corporation and proposes to mine 90.7 billion kg of coal over a 22-year period at this site (U.S. Geological Survey 1977b). The mine will produce 4.5 billion kg/yr of coal and will disturb a total of 5.13 km^2 of land for total operation.

The Pronghorn Mine, which will begin strip mining in 1979, will require approximately 0.42 million m^3/yr of water for domestic needs, dust suppression, equipment cleaning, fire control, and irrigation (U.S. Geological Survey 1977b). The water will be available from the exposed aquifers found in the coalbeds, which will supply close to 302.8 m^3/day of water (U.S. Geological Survey 1977b). In order to prevent mine runoff from directly contributing pollutants into Caballo Creek and the Belle Fourche River, the operating company will construct several impoundments and diversion ditches throughout the impacted area.

Reclamation--

Rehabilitation of disturbed mining areas will rest not only upon the potential of the land to return to its original state, but upon proper administrative policy. Efforts such as the Packer system of classification rate the rehabilitation potential of a region on the elements of soil (productivity and stability), vegetation (suitability and availability), precipitation (amount and seasonal distribution) and the potential moisture holding capacity of the land (Missouri River Basin Commission 1978b). These variables are combined to arrive at a numerical rating between +9 to -9 (very good to very poor). The mining areas in northeast Wyoming and western North Dakota (which include the Belle Fourche and Little Missouri River Basins) are highly variable in their potential for rehabilitation. The Missouri River Basin Commission (1978b) assigned a rating of +3.81 to western North Dakota tributary watersheds in and near the study area, and a rating of -0.47 to those in northeast Wyoming. This is primarily a result of the amount of rainfall each of the two areas receive.

Reclamation is particularly difficult in regions of low precipitation where sufficiently large quantities of water are not available to allow reestablishment of plant cover. Most of the rainfall in the study area falls between April and September when prevailing westerly winds deplete the soil moisture. This semi-arid environment places limitations on the availability of water for rehabilitation.

Future rehabilitation of energy resource areas will be of growing concern, and such legislation as the Wyoming Environmental Quality act of 1973 is being enacted to oversee most of the problems associated with mined area reclamation (Missouri River Basin Commission 1978b). Terms of the act require rehabilitation of surface-mined land to equal or better condition. Revegetation of disturbed lands, topsoil stockpiling and reuse, and the prevention of erosion and water pollution are also included under the Wyoming Environmental Quality Act (Missouri River Basin Commission 1978b).

Powerplants

The number of existing coal-fired powerplants in the Belle Fourche and Little Missouri River Basins is small. However, the potential for such development is high. The Neil Simpson Powerplant and the Wyodak Powerplant are the only two coal-fired electrical generation facilities in the area. The Neil Simpson Powerplant is owned by the Black Hills Power and Light Company and is located at the Wyodak Mine site in Wyoming. The plant currently has a generation capacity of between 25 and 30 MW and is burning about 0.36 million kg/day of coal (McMillion 1978). The plant uses an air-cooled system that requires an average of 35.9 m^3/day of water for blowdown purposes (V. Schields, Neil Simpson Powerplant, Gillette, Wyoming, Personal communication, 1978). This water is obtained from several wells in the area, the largest of which provides 0.4 m^3/min of water.

The Wyodak Powerplant is the largest air-cooled, coal-fired electrical generation plant in the country. Owned by the Pacific Power and Light and the Black Hills Power and Light Companies, the plant is located next to the existing Neil Simpson Powerplant and has a 330-MW generation capacity (U.S. Department of Interior 1974). Coal is consumed at Wyodak at the rate of 0.9 kg/KWH, or between 0.92 and 4.36 million kg/day, depending on megawattage output. Water consumption from blowdown is at a comparable rate to that of the Neil Simpson Powerplant (V. Shields, Neil Simpson Powerplant, Gillette, Wyoming, Personal communication, 1978). Power from both plants is distributed to Buffalo, Wyoming, and to Spearfish, South Dakota (U.S. Department of Interior 1974). Other plans for future power development in the study area include a 1,000 MW plant in northwest South Dakota, a 5,000 MW plant in southwest North Dakota in connection with existing coalbeds there, and a 5,000 MW plant in the eastern-central area of Montana (North Central Power Study Coordinating Committee 1971). In addition to coal generated powerplants, the Gillette area has plans underway for the development of several thermal generation powerplants.

Hydroelectric Power

Because of the intermittent streamflow that is characteristic of the study area, there are only two hydroelectric plants in the Belle Fourche and Little Missouri River Basins. Both of these plants are owned and operated by the Homestake Mining Company in South Dakota, which receives its power from them.

The Spearfish 1 Plant is located 8 km upstream from the town of Spearfish, South Dakota, on Spearfish Creek. This plant produces 24 million KW of electrical energy per year and has been in operation since 1909 (L. Jeffries, Homestake Mining Company, Lead, South Dakota, Personal communication, 1978). It is maintained with an average streamflow of 1.44 m^3/sec. The second plant, Spearfish 2, is located at Maurice, South Dakota, and provides Homestake Mining Company with 12 million KW annually. This plant has been producing since 1917 and is supported by an average streamflow of 1.38 m^3/sec.

Uranium

The first shipments of uranium from the Belle Fourche-Little Missouri River study area were during the 1940's, but shipments declined in the early 1960's when the market demand could be more profitably satisfied elsewhere (Missouri River Basin Commission 1978a). With resources again becoming increasingly scarce, the potential in the basin for production of uranium is once again growing.

The major North Dakota uranium resources are located in thin lignitic beds associated with sandstone ground-water aquifers. The only commercial production of the mineral from the Little Missouri Basin in this State is between the towns of Belfield and Amidon in southern Billings County (Missouri River Basin Commission 1978a). Other important outcrops occur in the Black Hills in South Dakota and in the Pumpkin Buttes region of northeastern Wyoming. The only active uranium mining operations in northeastern Wyoming, however, are located in the Cheyenne River Basin to the south of the present study area. Future developments in the Little Missouri-Belle Fourche Basins will depend on the interest in prospecting and cost of developing ore-producing plants.

PROPOSED DEVELOPMENT

Coal Gasification and Liquefaction Plants

There are currently no gasification plants in the area. However, future developments are in the planning stages and may be in operation in the 1990's (University of Oklahoma and Radian Corporation 1977a).

Production of gas and liquid fuels via the gasification and liquefaction processes will not be practical until after the 1990's because of the cost of production (Baria 1975b). After 1990-2000, availability of Federal funds coupled with exhausted or dwindling domestic reserves may lead to an expansion in coal gasification and liquefaction activity. Several plants are proposed throughout the Northern Great Plains in connection with expanding coal development. However, only six are in or near the Little Missouri-Belle Fourche study area (Table 15).

The Lurgi Pressure Gasification Process, the Synthane high Btu, IGT (Institute of Gas Technology) HYGAS gasification process, or the Synthoil coal liquefaction and Fisher-Tropsch synthesis are the most likely major processes to be used (University of Oklahoma and Radian Corporation 1977a). The Lurgi Pressure Gasification, HYGAS, and Synthane gasification processes produce high Btu synthetic gases and differ from the Synthoil liquefaction process, which produces fuel oils or gasoline (U.S. Environmental Protection Agency 1977a). Underground in situ gasification processes have also been examined and tested for feasibility by Lawrence Livermore Laboratories and the Federal Energy Research Development Administration. The Hoe Creek Project, located due south of Gillette in the Belle Fourche Basin, was initiated in October 1976 and continued for 11 days during which time 118 thousand kg of coal, or 16 percent of the fractured zone, was consumed (McMillion 1978). The study revealed that ground-water movement through the burned zone could be degraded by the byproducts of pyrolysis and the carbonization and coking of coals.

Water is a primary resource required for synthetic gas production. It is used for both the processing and cooling associated with each of the different methods (Table 16). In processing, the water is used to generate steam and supply hydrogen for reactions in the gasification/liquefaction processes (Northern Great Plains Resource Program 1974). Water is also utilized for ash quenching, sluicing, dust control, and reclamation (Baria 1975a). Whether ground water or surface water is used for further development will depend on its quality and availability. However, most of the proposed liquefaction-gasification plants plan to utilize ground water, which will deplete the shallower aquifers. The quality of these sources is poor and depletion will demand the use of new aquifers at greater depths. Whatever process is implemented, the water consumed per unit of energy produced through gasification is less than is consumed for continual power generation. Through gasification 7.08 x 10^3 Btu are produced for each cubic meter of water consumed, as compared with conventional steam electrical generation of approximately 1.4 x 10^3 Btu per cubic meter of water consumed (Northern Great Plains Resource Program 1974).

TABLE 15. PROPOSED GASIFICATION-LIQUEFACTION PLANTS IN OR NEAR THE BELLE FOURCHE-LITTLE MISSOURI RIVER BASIN STUDY AREA*

Company	Site	Planned Capacity (MMCMD)	Remarks
Carter Oil (G)	North of Gillette in Campbell Co.	7.08	Studies and planning began in 1974.
Panhandle Eastern Pipeline Company	Northeast of Douglas, Converse Co., Wyoming	7.64	Seeking water rights; construction postponed. Peabody's Rochelle Mine will supply coal at an estimated rate of 22.6 million kg/day. Current reports express doubt as to whether project will ever be constructed.
ERDA Hoe Creek Experiment (IG)	32 km south of Gillette, Wyoming	Experiments in progress	Explosive fracturing of coal at 45.7 m depth has produced 0.1 million kg of coal or 16 percent of the fractional zone.
Natural Gas Pipeline (G)	Dunn Co., North Dakota	21.2	
El Paso Natural Gas Co. (G)	S.W. North Dakota	14.6	
Exxon Oil (L)	N. Wyoming	3.6	Only one unit planned

G = Gasification, L = Liquefaction, IG = In situ gasification, MMCMD = Million m^3/day crude oil

*Modified from Corsentino (1976), Harza Engineering Company (1976), and McMillion (1978).

TABLE 16. ANTICIPATED WATER REQUIREMENTS FOR ENERGY FACILITIES IN THE LITTLE MISSOURI-BELLE FOURCHE STUDY AREA IN THE YEAR 2000 (Modified from University of Oklahoma and Radian Corporation 1977a)

Facility	Size	Anticipated Water Requirement ($m^3 \times 10^6$)
Power generation	3,000 MW (electricity)	46.1-51.8
Coal gasification (Lurgi)	7.08 million m^3/day	5.9-8.7
Coal gasification (Synthane)	7.08 million m^3/day	10.3-12.4
Coal liquefaction (Synthoil)	15.9 million liters	13.4-23.9
Coal mining	51,517 million kg/yr	1.5

TRANSPORTATION OF ENERGY RESOURCES

The dispersal of energy-related materials such as coal, oil, natural gas, and electricity constitutes a significant portion of the total environmental impact associated with energy development. Wyoming and North Dakota are major exporters of coal, gas, oil, and uranium which pose a unique problem, that of distance to point of delivery, when transportation systems are examined. Those energy resource shipments in the eastern United States, such as originate from the Appalachian and Illinois mines, generally traverse distances on the average of less than 186 km, with an occasional line of 310 km. If development occurs as planned in the Wyoming and North Dakota area, routes as long as 930 km may be common (Campbell and Katell 1975).

The primary mode of coal transportation will be by 100-car unit trains, each train capable of carrying 9.07 million kg of coal. Transport will be to terminals in Austin, Texas, Omaha, Nebraska, Chicago, Illinois, and Detroit, Michigan (Figure 8). The Pigs Eye Terminal, to be constructed on the Mississippi River at St. Paul, Minnesota, will provide a major rail-waterway transfer and loading facility for distribution to midwestern power utilities (U.S. Bureau of Indian Affairs 1974). Use of coal slurry lines in transport of coal is also proposed for the Wyoming coal development area. However, large volumes of water are needed for extensive slurry development, and because of the physical and legal limitations on availability of water in the Little Missouri and Belle Fourche Basins, this mode of transport is not likely to be developed in the near future.

Environmental impacts resulting from transportation of energy resources are demonstrated in the proposals by Burlington Northern Railroad and North Western Transportation Company. The company intends to build and operate a new railroad route between Gillette and Douglas that will disturb

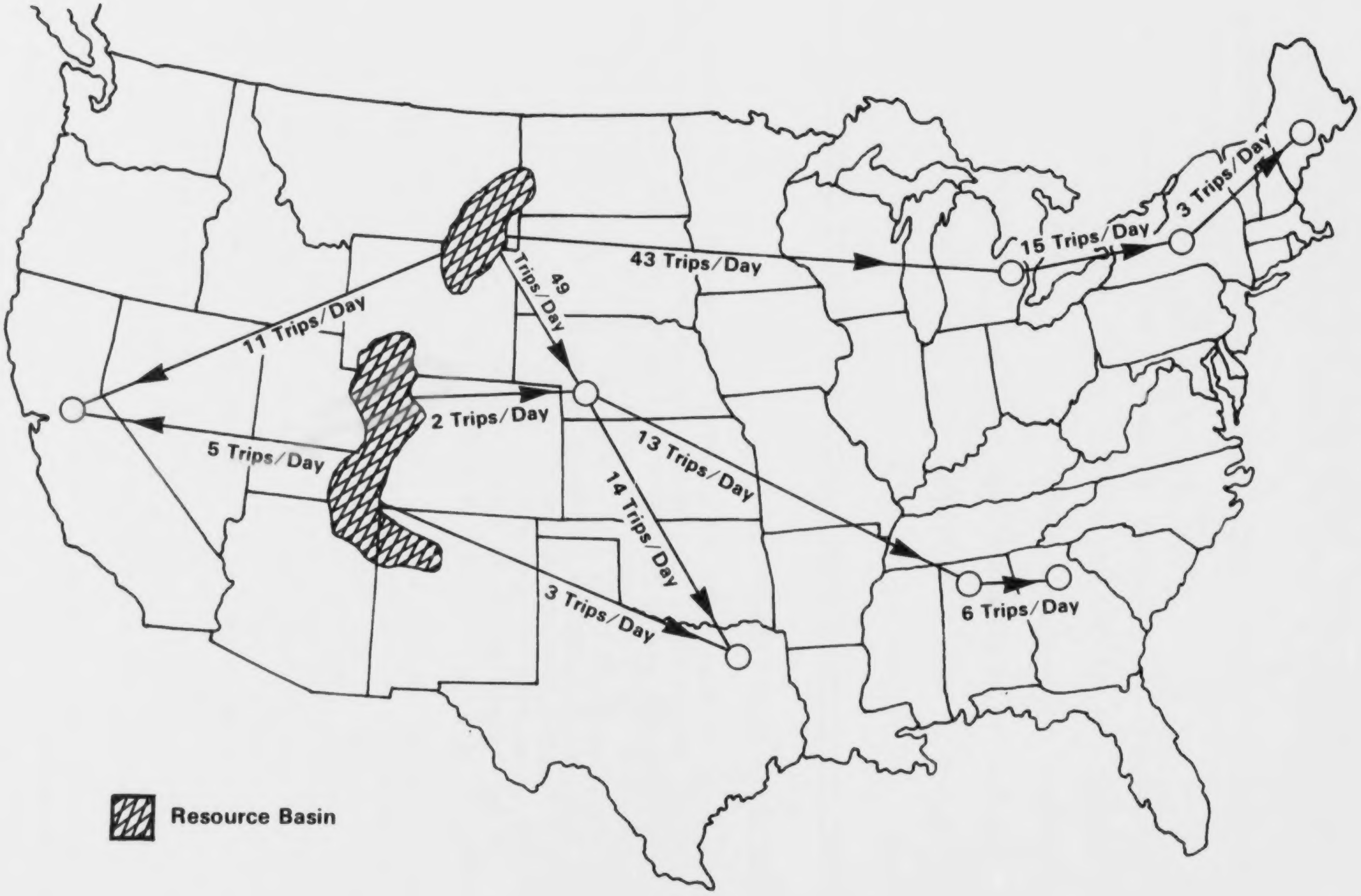

3 Trips/Day
15 Trips/Day
43 Trips/Day
49 Trips/Day
11 Trips/Day
2 Trips/Day
5 Trips/Day
13 Trips/Day
14 Trips/Day
3 Trips/Day
6 Trips/Day
▨ Resource Basin

Figure 8. Unit coal energy to be transported from the Western United States by the year 2000. (Modified from University of Oklahoma and Radian Corporation 1977a).

approximately 10 km^2 of land and alter the existing drainages of a number of rivers including Caballo Creek, the Belle Fourche River, Coal Creek, and Little Thunder Creek during the construction of bridges. The development of these transportation routes will be an important contribution to the area because the existing rail network is now inadequate to provide for future dispersal of energy resources.

Gas and liquid fuels (crude oil, shale oil, and coal syncrude) will be transported via pipeline to refineries throughout the country (Figure 9). Electrical power will be distributed from the coal-fired generation facilities at Gillette to southern and midwestern populations (Figure 10).

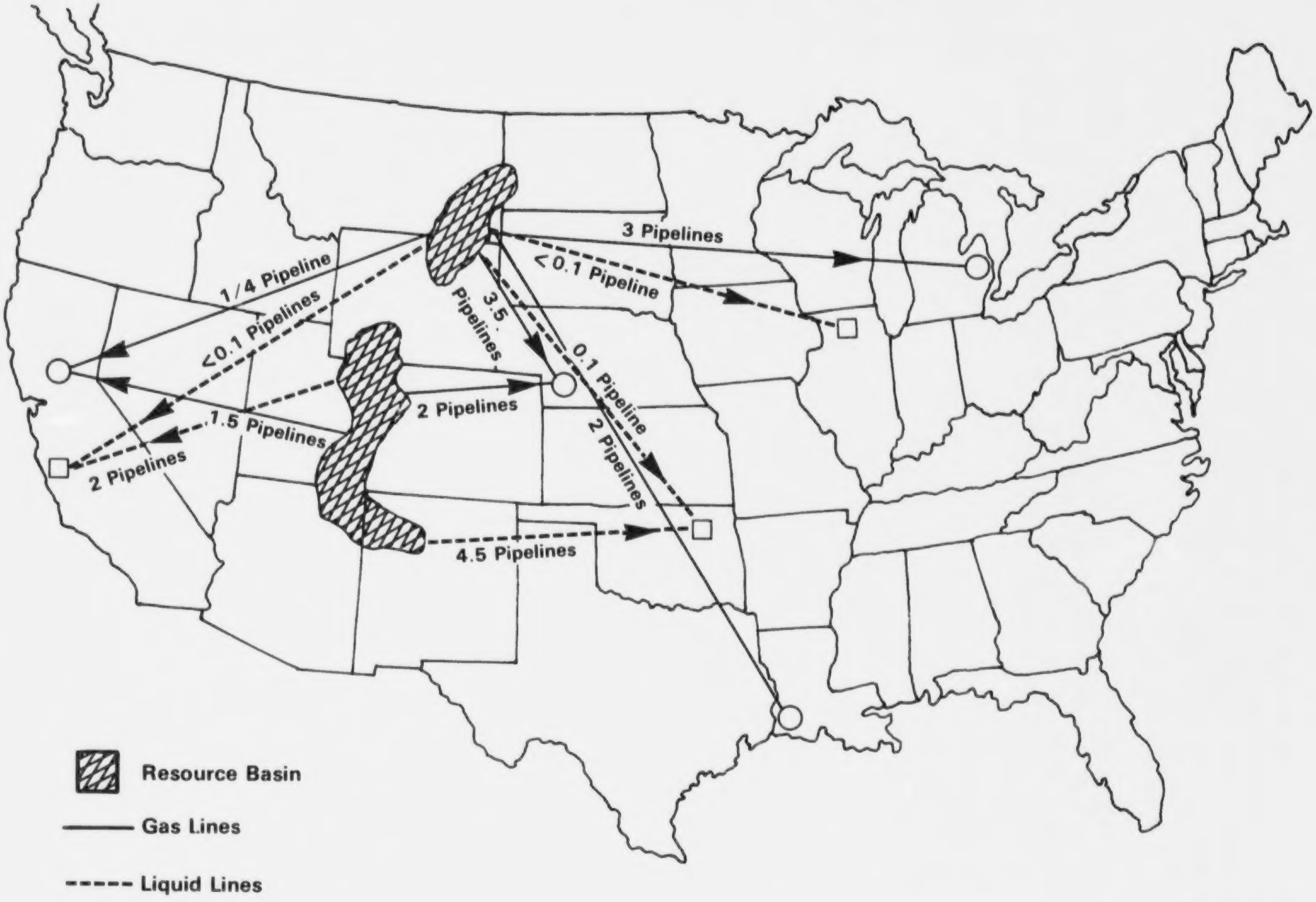

3 Pipelines
< 0.1 Pipeline
1/4 Pipeline
<0.1 Pipelines
3.5 Pipelines
0.1 Pipeline
2 Pipelines
2 Pipelines
1.5 Pipelines
2 Pipelines
4.5 Pipelines
Resource Basin
Gas Lines
Liquid Lines

Figure 9. High Btu gas liquid (crude oil, shale oil, coal syncrude) pipelines proposed by the year 2000 for the Western United States (capacity of each pipeline is 28 million m^3/day). (Modified from University of Oklahoma and Radian Corporation 1977a).

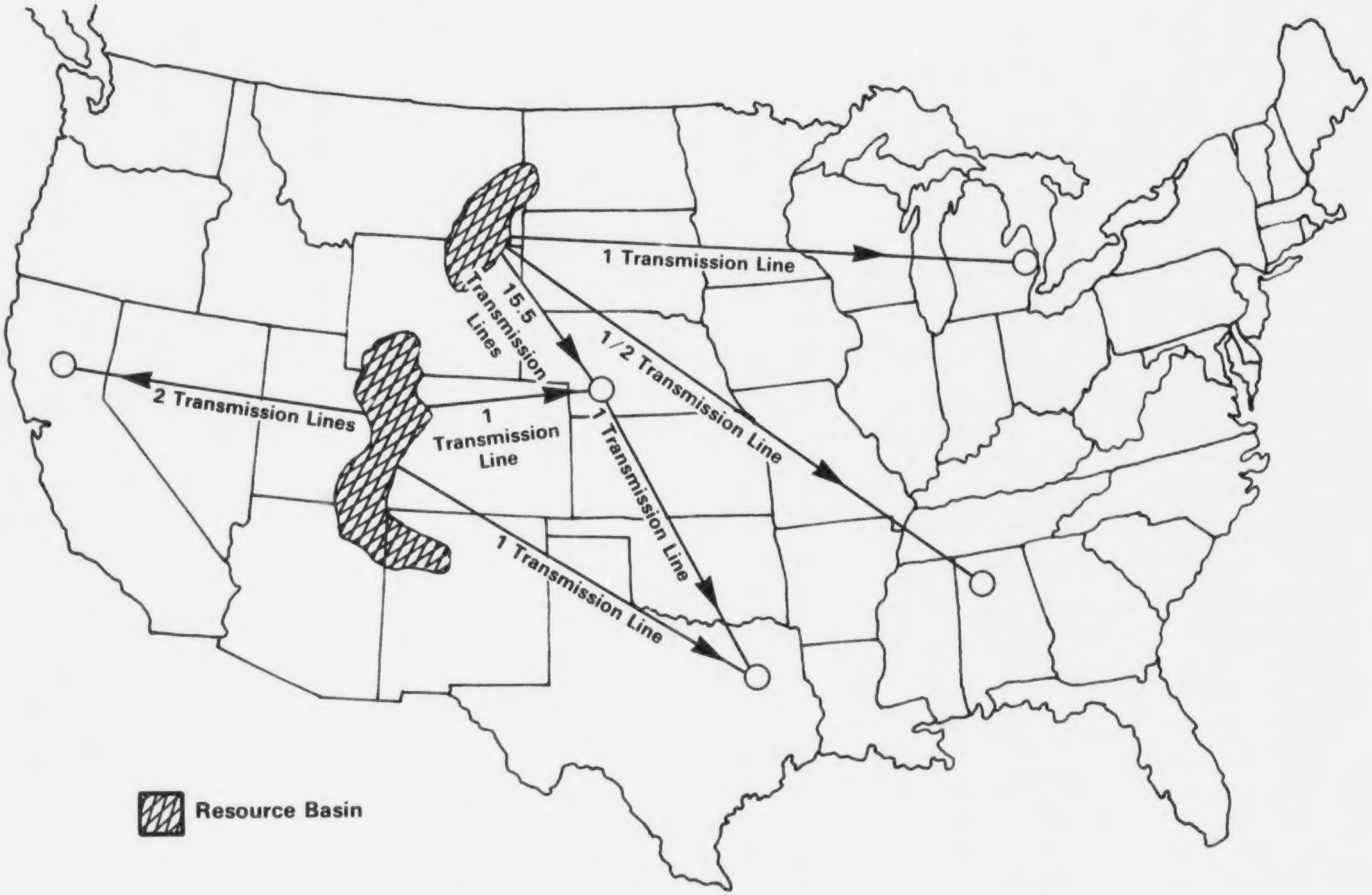

1 Transmission Line
15.5 Transmission Lines
1/2 Transmission Line
2 Transmission Lines
1 Transmission Line
1 Transmission Line
1 Transmission Line
▨ Resource Basin

Figure 10. Electricity expected to be transported from the Western United States by the year 2000. (Modified from University of Oklahoma and Radian Corporation 1977a).

6. OTHER SOURCES OF POLLUTION

EROSION

Erosion in the Little Missouri and Belle Fourche River Basins is dependent on several environmental factors, some of which vary through the year. Weather changes, topography of the area, types of soil, land use and management practices, and seasonal availability of a canopy protection of crops and pastureland all influence the degree of erosive action present (Northern Great Plains Resource Program 1974). The Gillette mining area is unique in that much of the surrounding terrain is relatively erosion-resistant because of a protective capping of clinker formed by the burning of thick coalbeds (Smith 1972).

There are three major types of erosion--upland erosion, sheet erosion, and channnel erosion (Missouri Basin Inter-Agency Committee 1969b). The first--upland erosion--is characterized by rills or channels formed in the surrounding hillsides and is largely influenced by the amount of vegetation, amount of rainfall, and type of soil present. The second type--sheet erosion--is the result of rainfall and snowmelt upon the soil. The runoff forms sheets of water that carry large quantities of sediment. This erosion type is often seen as a result of summer storms that subject localized areas to intense precipitation. This rapidly exceeds the land's capacity to absorb the water and results in surface runoff. The third form of erosion--channel erosion--acts on mature stream channels, and sediment yields from this type are usually a result of eroding channel banks (Missouri Basin Inter-Agency Committee 1969b). In the semiarid study area, many of the stream channels are dry much of the year and are youthful in nature. During periods of intense rainfall, flash flooding may occur wherein large volumes of runoff result in active downcutting and clearing the channel of collected debris and shrubbery.

Pollutants of nitrogen, phosphorus, potassium, and organic wastes are common in agricultural runoff, which is by far the major contributor to the increased sediment yields of both the mainstem Belle Fourche and Little Missouri Rivers (McMillion 1978). Coal mining activities also increase erosion in the basins through such activities as removal of overburden material, stockpiling, and relocation of soil. Blasting increases the amount of dust suspended in air that, together with windblown coal dust and ash from transportation, storage, and disposal areas, might later settle in a waterway or reservoir. Other erosive mechanisms associated with mining include the continual traffic of large machinery and destruction of natural vegetative cover (U.S. Department of Interior 1974). The erosive hazards associated with coal mining are increased during periods of drought that are occasionally broken by episodic, high rainfall events.

Erosion impact can, however, be reduced by controlling the amount of vegetation and type of soil present. The creation of surface reservoirs to control flooding is another commonly used method to reduce sedimentation impact from mining areas.

MINE DRAINAGE

The impact of mine effluents on water quality will be of growing concern in the Belle Fourche-Little Missouri River Basins as the number of energy development facilities increases. Potential sources of water quality contamination associated with mining activities include loading, crushing, and screening facilities, access and hauling roads, equipment maintenance and building areas, overburden removal and deposition, construction of water control facilities, stream diversions, and population influx as a result of increased availability of jobs. Each of these sources poses a specific environmental threat to the quality of the basin waters.

The acid mine drainage from coal extraction common in the Eastern United States is not a problem in the Little Missouri and Belle Fourche River Basins where the sulfur content of coal is generally less than 1 percent (Northern Great Plains Resource Program 1974) and soils are generally alkaline. In this area, total dissolved solids and suspended solids from erosion of the disturbed areas are the most obvious potential pollutants. Pollution from ground-water aquifers may result when the aquifers are intercepted during mining operations producing a net inflow and accumulation of water in the active pit. Surface runoff, or shallow ground water such as that from irrigation return flows, may percolate through mine spoil areas resulting in increased salts, especially sulfates or heavy metals (Table 17). Mining operations may also directly discharge toxic substances into surrounding surface water supplies. Such has been the case with the Homestake Gold Mine; water quality evaluations of Whitewood Creek below the mine reveal concentrations of cyanide, arsenic, mercury, and suspended sediments that are sufficiently high to damage the aquatic biota of the creek (U.S. Environmental Protection Agency 1971a).

TABLE 17. MAJOR POTENTIAL ELEMENTAL POLLUTANTS ASSOCIATED WITH COAL MINING ACTIVITIES IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS (Modified from McMillion 1978)

Calcium	Cadmium
Magnesium	Chromium
Chloride	Arsenic
Boron	Lead
Fluoride	Molybdenum
Iron	Vanadium
Manganese	Uranium
Zinc	Thorium
Copper	Radium
Selenium	Mercury

URBAN RUNOFF

In association with increased industrial development in the Belle Fourche and Little Missouri Basins, rapid population growth may be expected. This influx of people increases the likelihood of contributions to the basins from nonpoint urban runoff as well as augmenting the consumptive water demands and burden on existing sewage facilities. The area surrounding Gillette, Wyoming, is expected to experience the greatest growth within the study basins as a result of the expanding mining industry.

Nonpoint urban runoff is largely produced by precipitation, which washes a population center flushing a great variety of city wastes into the nearest water system. This runoff is greatest during periods of episodic, heavy rainfall and typically is high in nutrients and suspended sediments. Combined storm and domestic sewer overflow is a common urban source of organic pollution to the aquatic ecosystem. Animal wastes, fertilizers, pesticides, and general street debris are other common urban pollutants.

7. WATER REQUIREMENTS

WATER RIGHTS

The Northern Great Plains area, during the 19th century, adopted a laissez-faire philosophy toward water allocation and development (University of Oklahoma and Radian Corporation 1977b). A traditional "senior take all" appropriation doctrine evolved in which the first individual to divert water to a beneficial use established a dated and quantified right to first use of the water. All stream users thus establish dated rights, and as water supplies decrease those bearing later priority dates are shut off until senior rights are met (Lord et al. 1975). In light of increasing population growth and water demands, however, Federal and State regulations to control use have been established; it is probable that legal rights to utilize water will become a major factor in regional decisions regarding future energy development.

The Belle Fourche River Compact of 1944, which provides the basis for dividing water of the Belle Fourche River between the States of Wyoming and South Dakota, is the primary Federal law governing distribution of surface waters in this study area. In this law, those water rights and supplies established prior to 1944 are recognized as first priority (Wyoming State Engineers Office 1973). The remaining unused and unappropriated waters are divided so that Wyoming is allocated 10 percent of the Belle Fourche River flow and the remainder goes to South Dakota. Other provisions of the compact specify that Wyoming is allowed unlimited development of storage reservoirs with less than 25 thousand m^3 capacity for stock-watering purposes, but no reservoirs with greater than 1 million m^3 capacity may be constructed in Wyoming if they will be used solely by that State for its own needs (Wyoming State Engineers Office 1972). If a reservoir, primarily designed to satisfy irrigation demands for South Dakota, is constructed on the Belle Fourche River in Wyoming, the State of Wyoming is entitled to 10 percent of the reservoir storage regardless of size.

There is at present no interstate compact for allocation of surface waters in the Little Missouri River Basin (Missouri River Basin Commission 1978a). In the 1950's a Little Missouri River Compact was authorized by Congress, and the involved States (Wyoming, North Dakota, South Dakota, and Montana) convened to discuss terms of the proposed agreement. However, in light of the highly unpredictable flows of the Little Missouri River, the need for an intensive hydrological study of the river, and the need for a complete water right inventory of the basin in all four States, interest in the compact cooled and negotiations were brought to a close (Wyoming State Engineers Office 1972). Since that time, as a result of the National Wild and Scenic Rivers Act, the Little Missouri River has been designated as a State scenic and recreational river from the South Dakota State line to its confluence with the Missouri River at Garrison Reservoir (Missouri River Basin Commission 1978a). Such action will severely limit the expansion of energy development in this stretch of the Little Missouri and thus will preserve it for future recreational and wildlife-associated needs that may have otherwise been destroyed.

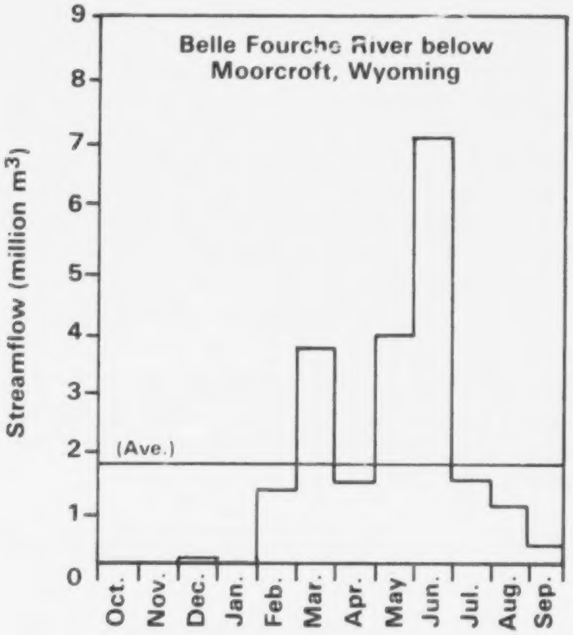
WATER AVAILABILITY

The Wyoming State Engineers Office (1972) has estimated that an average water supply of 107 million m^3/yr is available for apportionment in the Belle Fourche River Basin. After allowing for stock and domestic usage (which is unlimited by compact law) and evaporation loss in Keyhole Reservoir, it is calculated that Wyoming is entitled to 9 million m^3/yr consumptive use of surface water in that basin (Wyoming State Engineers Office 1972). Resources available from Keyhole Reservoir are sufficient to provide this annual supply.

In the Little Missouri River Basin, there is no known estimate on the annual water supply that can be depended upon for reapportionment. In Wyoming, predictable surface flows only occur in the early spring as a result of snowmelt, and virtually all of this water is presently committed to irrigation and stock usage. Studies on flow variability in the river in South Dakota show that at the Camp Crook station an average flow of only 0.01 m^3/sec during about three months annually can be expected every five years (South Dakota Department of Natural Resources Development 1972). Once every two years, flows less than 0.03 m^3/sec for a one-month stretch can be expected at this site. All of these data suggest that the Little Missouri River cannot be relied upon to provide much flow for year-round consumptive water use without implementation of additional storage.

Monthly hydrographs (Figure 11) show the variation in streamflow for the Belle Fourche River in Wyoming. Since runoff is generally highest in May and June and crop needs are greatest during July and August, reservoir storage is also necessary in this basin to assure adequate water supplies for the latter portion of the growing season (Wyoming State Engineers Office 1972). The hydrograph for the Belle Fourche River at the Wyoming-South Dakota State line reflects the positive impact of Keyhole Reservoir on the downstream water availability of that river.

The average annual discharge from the Little Missouri River at Watford City, North Dakota, is 541 million m^3; the maximum recorded runoff was 1.5 billion m^3 in 1971, and the minimum recorded annual discharge was only 72 million m^3 in 1961 (Missouri River Basin Commission 1978a). The maximum flow recorded at this site was 3,115 m^3/sec (North Dakota State Water Commission 1975a). The average annual discharge of the Belle Fourche River is 326 m^3/yr (Riis 1977). Flows as great as 1,277 m^3/sec were recorded in 1964 at Elm Springs, South Dakota, and periods of zero discharge have been recorded at that same site on numerous occasions (Riis 1977).



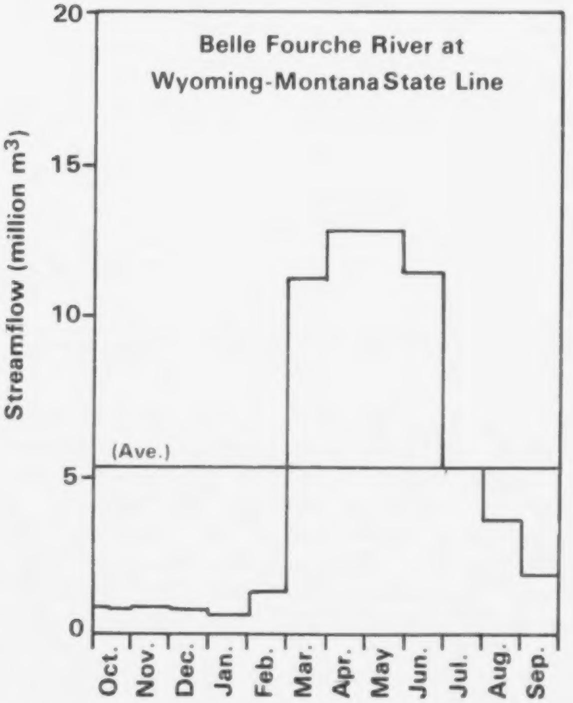


Figure 11. Mean monthly variations in streamflow in the Belle Fourche River in Wyoming. (Modified from Wyoming State Engineers Office 1972)

The mean annual consumptive use and evaporation loss in the Belle Fourche River Basin in Wyoming totals 25 million m^3/yr and in the Little Missouri Basin totals 6 million m^3/yr (Table 18). Consumptive use in the Belle Fourche Basin in South Dakota includes an average 2 million m^3 livestock depletion and 39 million m^3/yr evaporation losses. In the South Dakota portion of the Little Missouri Basin, an average 1.6 million m^3/yr of water is consumed for beneficial use (Table 19), and in North Dakota mean annual depletion totals 16 million m^3/yr for irrigation, 508 thousand m^3/yr for recreation, and 361 thousand m^3/yr for stock water. Municipal and rural domestic supplies in this region are largely met by ground-water resources (Missouri River Basin Commission 1978a).

TABLE 18. ESTIMATED ANNUAL WATER YIELD, CONSUMPTIVE USE, AND EVAPORATIVE LOSS OF SURFACE WATERS IN THE BELLE FOURCHE AND LITTLE MISSOURI RIVER BASINS, WYOMING, 1948-68 (Modified from Wyoming State Engineers Office 1973)

	Belle Fourche Basin ($m^3 \times 10^6$)	Little Missouri Basin ($m^3 \times 10^6$)
Total yield in Wyoming	119.3	43.7
Consumptive use		
Irrigation	1.8	2.2
Industrial	1.2	--
Municipal, domestic, stock	1.2	1.2
Reservoir evaporation	20.7	2.6
Net outflow at Wyoming State line	94.4	37.7

Although the data for beneficial-use depletions are very incomplete for the study basins from State to State, what data are accessible suggest water availability will be a major factor limiting increased energy resource development in the future. The total average consumptive use for the Belle Fourche Basin in Wyoming, plus known depletion from evaporation and livestock in South Dakota, are alone nearly equal to the minimum recorded annual discharge for that river. Certainly there will be times when adequate water supplies will exist to satisfy all consumptive demands. However, in planning for future development in the basins, it will be necessary to determine definitively how much water can be reliably counted on as available from year to year.

TABLE 19. SUMMARY OF AVERAGE ANNUAL WATER USE IN THE LITTLE MISSOURI RIVER BASIN, SOUTH DAKOTA (Modified from South Dakota Department of Natural Resources Development 1972)

Beneficial Use	Diversion ($m^3 \times 10^3$)	Consumption ($m^3 \times 10^3$)
Agricultural		
Rural household	15.7	4.9
Livestock use	246.7	246.7
Farm pond evaporation	752.4	752.4
Full season irrigation	357.7	233.1
Spreader system irrigation	589.6	370.0
Municipal	5.5	1.8
Industrial	0	0
Recreation, fish, and wildlife	0	0
Total	1,967.6	1,608.9

LITTLE MISSOURI AND BELLE FOURCHE RIVER WITHDRAWALS

Energy Resource Development

Mining and other energy development activities in the Belle Fourche and Little Missouri River Basins will have a significant environmental impact on water resources of the area. Surface mining of coal requires approximately 54.2 to 61.8 thousand liters of water per kilogram of coal mined (Adams 1975). Conversion of coal into electricity or into natural gas and crude oil requires large quantities of water (Table 20), particularly if gasification and liquefaction processes are implemented. Transport of coal to powerplants, if done by coal slurry line, can require an additional 2.5 to 3.7 million m^3/yr of water to provide slurry to a 1,000 MW electric generating plant (Adams 1975). Nonenergy mineral industries, such as mining of sand and gravel or stone, deplete an annual average of 18 thousand m^3/of water in northeastern Wyoming (Missouri River Basin Commission 1978b). Mineral industries in the Black Hills area of South Dakota consume 19.4 million m^3/yr (Gries 1974). All of these water demands are immense since many streams in the resource area are dry much of the year and ground-water supplies must be carefully mined to avoid depletion of usable aquifers at a rate in excess of recharge capacity. About half of the needed water consumed by industry in the Little Missouri and Belle Fourche River Basins is supplied by ground-water resources.

TABLE 20. WATER USE FOR COAL-RELATED ACTIVITIES (Modified from Missouri River Basin Commission 1978b)

Type of Activity	Liters of Water per kg of Coal
Coal mining and unit train transport	0.04
Coal mining and slurry pipeline transport	0.98
Mine-mouth electric powerplants (consumptive use)	
Closed cooling	0.42
Stream cooling	2.09
Ponds	2.50
Evaporative cooling towers	3.55
Coal liquefaction	6.80
Combination liquefaction-gasification	7.09
Coal gasification*	10.85
Vegetative reestablishment with irrigation**	0.17

*Recent technological advances may reduce these figures to half of the values shown.

**Assuming an average production of 6.7 billion kg of coal per surface km^2 and an irrigation requirement averaging 1.2 million m^3 per km^2 over a three-year period. Most reclamation in northeastern Wyoming has been accomplished without irrigation, although it is considered here to assure its availability should irrigation water be needed.

For purposes of full-scale industrial development in the study basins, it is likely that transport of water via aqueducts will be more economical than transport of coal to the water sources, since coalbeds subject to development lie a good distance from major water supplies (U.S. Bureau of Reclamation 1972). A number of major aqueducts have been proposed to transport water to the Gillette area from the Bighorn River and Yellowstone River, and smaller diversions from the North Platte, Green River, and Boysen Reservoir. The most likely of these proposals is diversion from the Yellowstone near Miles City, Montana, to Gillette with water service to intervening coalfields (U.S. Bureau of Reclamation 1972). With such a diversion in effect, 2.6 billion m^3/yr of water would be routed from the Yellowstone River, past Pumpkin Creek and Broadus, and on to Gillette. The construction of additional storage facilities would also be needed to insure availability of water from the Yellowstone during late summer water shortages since the Gillette coalfields lie 209 to 322 km from the Yellowstone River.

Irrigation

In the Upper Missouri Basin, agriculture, primarily irrigation, accounts for two-thirds of the surface water withdrawals and over 90 percent of the consumptive water use (Lord et al. 1975). In the Little Missouri and Belle Fourche River Basins, irrigation accounts for nearly all water diverted and consumed; in northeastern Wyoming irrigation consumes 194 million m^3 of water annually, which represents over 80 percent of the water consumption in the area (Missouri River Basin Commission 1978b).

In the States of Wyoming and South Dakota, approximately 57.9 km^2 of land in the Belle Fourche River Basin are irrigated, and 98.2 million m^3 of water are used annually to satisfy these agricultural needs (Table 21). Over 28.2 million m^3/yr of water from the Little Missouri Basin are applied to irrigate 61.3 km^2 of land throughout North Dakota, South Dakota, and Wyoming. The irrigation season in the Little Missouri and Belle Fourche Basins typically extends from April through October. However, July, August, and September are the months of heaviest water application, with over 84 percent of the total diverted water used during this period (Riis 1977). Most of the water used for irrigation is obtained from surface resources; only 9 percent of the water diverted for irrigation purposes in the Belle Fourche River Basin is from ground-water supplies (Riis 1977).

Construction of reservoirs to store spring runoff for late season irrigation use is the most likely solution to agricultural-related water shortages in the study area. The largest such project already existing in the basins is the Belle Fourche Irrigation Project in South Dakota, which is supplied with water from Belle Fourche Reservoir. This reservoir is located on Owl Creek but diverts water from the Belle Fourche River to irrigate a maximum of 231.0 km^2 of land (Riis 1977). In 1975, the Belle Fourche Project applied 70.6 million m^3 of water for irrigation of 217 km^2 of land (Riis 1977). A number of other reservoirs have also been constructed in the study basins primarily to meet agricultural demands for water during low runoff periods (Table 22).

Irrigation will continue to be the dominant water use in the study basins even if energy development reaches maximum projected levels (Missouri River Basin Commission 1978b). The rate of water consumption for irrigation purposes should remain fairly constant, however, since industrial developers will utilize most of the presently unallocated water supplies (Wyoming State Engineers Office 1972).

Municipal and Industrial

There are a variety of additional requirements for water in the Little Missouri and Belle Fourche River Basins. These include domestic, manufacturing, governmental, and commercial needs. Although there are many municipal and industrial users in the study area (Tables 23 and 24), surface water consumption related to these systems is relatively minor. The Missouri Basin Inter-Agency Committee (1971a) reports that in 1965 the entire Western Dakota Subbasin (which includes the Little Missouri and Belle Fourche Rivers) contained approximately 314,000 public and private water systems but annually

TABLE 21. APPROXIMATE AREA AND ANNUAL WATER USE FOR IRRIGATION IN THE BELLE FOURCHE AND LITTLE MISSOURI RIVER BASINS*

State	Belle Fourche		Little Missouri	
	Km^2	Million m^3 of Water	Km^2	Million m^3 of Water
Montana	--	--	?	?
North Dakota (1975)	--	--	27.0	16.1
South Dakota (1975)	291.0	89.3	2.9	0.6
Wyoming (1972)	26.5	8.9	31.4	11.5

*Modified from Missouri River Basin Commission (1978a), North Dakota State Water Commission (1975a), Riis (1977), South Dakota Department of Natural Resources Development (1972), and Wyoming State Engineers Office (1972).

TABLE 22. MAJOR EXISTING RESERVOIRS USED PRIMARILY FOR IRRIGATION PURPOSES IN THE LITTLE MISSOURI-BELLE FOURCHE STUDY AREA*

Reservoir Name	County/State	River Location	Storage Capacity ($m^3 \times 10^6$)
Bradac Reservoir	Bowman, North Dakota	Unnamed stream	0.25
Uekert Reservoir	Golden Valley, North Dakota	Unnamed stream	0.14
Stone #2	Campbell, Wyoming	Bonepile Creek	1.90
Gillette Reservoir	Campbell, Wyoming	Stonepile Creek	3.50
Keyhole Reservoir	Crook, Wyoming	Belle Fourche River	234.00
Belle Fourche Reservoir	Butte, South Dakota	Owl Creek	236.00
Warhorse Reservoir	Carter, Montana	Box Elder Creek	23.70

*Modified from Missouri Basin Inter-Agency Committee (1969a), North Dakota State Water Commission (1975a), and Missouri River Basin Commission (1978b).

TABLE 23. DOMESTIC AND MUNICIPAL WASTE TREATMENT FACILITIES IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS**

Source and Location	Existing Treatment	Receiving Waters
Wyoming		
Gillette	Activated sludge with aerobic digesters	Stone Pile Creek
Sundance	Stabilization pond	Sundance Creek
Hulett	Oxidation ditch	Belle Fourche River
Carson's Mobile Home Park (Gillette)	Package plant plus chlorinator	Dry drainage to Donkey Creek
Wyodak Development Corporation	Stabilization pond	Donkey Creek
Devils Tower	2-cell lagoon	Dry draw to Lytle Creek
Moorcroft	1-cell pond	Unnamed draw to Belle Fourche River
Wyoming Highway Dept. Moorcroft Rest Area	Package plant	Unnamed tributary to Belle Fourche River
USDI Fish Genetics Lab. (Beulah)	Stabilization pond	Sand Creek
South Dakota		
Spearfish	Tricking filter	Spearfish Creek
Lead	none*	Whitewood Creek
Deadwood	none*	Whitewood Creek
Belle Fourche	Stabilization pond	Belle Fourche River
Sturgis	Stabilization pond	Bear Butte Creek
Whitewood	Stabilization pond	Whitewood Creek
Nisland	Imhoff	Belle Fourche River
Newell	Stabilization Pond	Deadman Creek
Montana		
Wibaux	Primary septic	Beaver Creek
Ekalaka	Activated sludge	Russell Creek
North Dakota		
Marmarth	Primary septic	Little Missouri River
Medora	Stabilization pond	Little Missouri River
Watford City	Stabilization pond	Cherry Creek

*Activated sludge plant now under construction; anticipated completion date February 1979. This plant will release treated effluent to land.

**Modified from U.S. Environmental Protection Agency (1971b), Wyoming State Engineers Office (1972), and Missouri River Basin Commission 1978b).

TABLE 24. INDUSTRIAL DISCHARGERS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS*

User	Receiving Stream
Amax Coal Corporation sedimentation basin	Caballo Creek
Wyodak Resources Development Corporation	Donkey Creek
Black Hills Power and Light Company	Donkey Creek
Sunoco	Belle Fourche River
Lead Mine	Donkey Creek
Homestake Mine	Whitewood Creek

*Modified from Wyoming State Engineers Office (1972) and Missouri River Basin Commission (1978b).

withdrew an average of only 30.8 million m^3 of water for municipal and rural domestic use. An additional 35.8 million m^3/yr of water in this subbasin is required to meet industrial demands (Missouri Basin Inter-Agency Committee 1971a).

Water demands for municipal and industrial purposes in the entire Little Missouri and Belle Fourche River Basins alone is not known at this time. However, municipal and industrial demands in Wyoming are estimated to consume an average of 2.4 million m^3/yr and 1.2 million m^3/yr, respectively, in the Belle Fourche and Little Missouri Basins (Table 18). In the Little Missouri Basin municipal demands consume 1.8 thousand m^3/yr in South Dakota (Table 19) and 2.1 million m^3/yr in North Dakota (Missouri River Basin Commission 1978a). Municipal needs use 3.5 million m^3/yr of water from the Belle Fourche Basin in South Dakota, and industrial demands (over 80 percent of which are related to activities in the Homestake Mine) use an average of 8.8 million m^3/yr (Riis 1977).

In addition to the consumptive impact on usable water, a large proportion of municipal and industrial diversions are returned to nearby streams, and pollutants from these return flows can substantially impact downstream users. Municipal areas in the Little Missouri and Belle Fourche Rivers utilize several wastewater facilities to reduce this impact. The large towns generally are served by trickling filters, activated sludge, and oxidation ponds and ditches; smaller communities are usually served by private septic tanks for sewage disposal. Industrial dischargers within the basin areas are predominantly associated with the mining industries and must treat effluents to prevent contamination of surface and ground-water supplies with salts and toxic elements. Although surface water withdrawal requirements are presently low in the study basins, future water requirements may increase as the result of population growth, especially in those areas with rapidly expanding energy development and mining activities such as around Gillette. The Missouri River Basin Commission (1978a) reports that between the years 1975 and 2000, municipal and rural domestic water consumption in northeast Wyoming could increase 11.7 million m^3/yr, and industrial-related water consumption could increase 126.4 million m^3/yr.

Fish and Wildlife

Water allocations to support fish and wildlife activities are required for refuges, wetlands, management areas, fish hatcheries, impoundments, and the maintenance of instream flows. The Missouri Basin Inter-Agency Committee (1971b) has projected that in the entire Missouri River Basin, from 1980 to 2000, surface water depletions associated with wetlands and fish and wildlife will increase from 218.3 million m^3 to 578.5 million m^3 above present levels of consumption. It is not known at this time what present levels of consumption related to fish and wildlife are in the Missouri River Basin, nor is that information completely available for the individual basins under study in this report. At any rate, fish and wildlife are relatively small water "consumers," and most water depletions can be attributed to hatchery facilities.

In the Belle Fourche River Basin in South Dakota, there are seven fish hatcheries with water rights for commercial fish culture. Collectively these use approximately 20.7 million m^3/yr of water (Riis 1977). Two of the largest users in the basin are the Spearfish National Fish Hatchery on Spearfish Creek and the McNenny Trout Hatchery on the Redwater River (Missouri Basin Inter-Agency Committee 1969a). The present consumptive uses assigned directly to recreation and fish and wildlife activities in Wyoming and North Dakota are small enough that watering ponds scattered throughout the area, which are supplied from the runoff of natural wetlands, provide adequate water supplies (Missouri Basin Inter-Agency Committee 1969a). By 1980, however, it is expected that 230 million m^3/yr of water will be required in the Little Missouri River at Watford City to meet instream flow requirements (Missouri River Basin Commission 1978a).

Livestock

Livestock account for a substantial portion of the agricultural-related water use in the Little Missouri and Belle Fourche River Basins. Table 25 shows the 1965 consumptive and evaporative losses associated with livestock facilities in the Western Dakota Subbasin of the Missouri River, as well as projected consumption levels to the year 2020. Surface water supplies can be expected to continue to satisfy most livestock demands in this area; the Missouri Basin Inter-Agency Committee (1971a) reports 70 percent of the 1965 livestock water demands were met by surface water in this subbasin and

TABLE 25. PROJECTED AVERAGE ANNUAL LIVESTOCK WATER USE IN THE WESTERN DAKOTA SUBBASIN (Modified from Missouri Basin Inter-Agency Committee 1971a)

Year	Source		# of Stockponds	Water Depletion	
	Surface Water (percent)	Ground Water (percent)		Evaporation (million m^3)	Livestock Consumption (million m^3)
1965	70	30	56,000	254	36
1980	71	29	67,000	254	59
2000	71	29	73,000	254	85
2020	71	29	75,000	254	116

projects that by the year 2000 surface water resources will supply 71 percent of the areal livestock needs.

It has been estimated that livestock consume an average 2 million m^3/yr and 247 thousand m^3/yr of water from the Belle Fourche and Little Missouri River Basins, respectively, in South Dakota (Riis 1977; South Dakota Department of Natural Resources Development 1972). An additional 752 thousand m^3 are lost in the Little Missouri Basin in South Dakota as a result of evaporation from stock ponds (South Dakota Department of Natural Resources Development 1972). Stock water in these basins is furnished by both surface and ground-water supplies. Much of the water used is stored in small ponds and impoundments that supplement surface flows in the intermittent stretches of the Little Missouri and upper Belle Fourche Rivers. Discharges from oil field operations in northeastern Wyoming are another important source of water for livestock (Wyoming State Engineers Office 1972) and at times provide the only water available to this arid region. Use of these discharges may increase in the Belle Fourche River, since future mining operations in Wyoming could in some cases disrupt drainage patterns sufficiently to destroy existing stock-watering impoundments in the mine areas.

IMPORTATION OF WATER

There are several plans proposed to import water to the area near and south of Gillette, Wyoming (Figure 12). Some of the possible routes include diversion of water from Boysen Reservoir on the Bighorn River, from the Yellowstone River at Miles City, from Bighorn Lake, or from the North Platte River, or the importation of water from Oahe Reservoir on the Missouri River in South Dakota (University of Oklahoma and Radian Corporation 1977a). All of these proposals are still in the tentative stage and dependent on future water right decisions and actual level of energy development achieved in the Little Missouri and Belle Fourche River Basins.

WATER AVAILABILITY VERSUS DEMAND

The State of South Dakota has been allocated 90 percent, and the State of Wyoming 10 percent, of the annual runoff of the Belle Fourche River as part of the Belle Fourche River Compact. At present there is no interstate compact for allocation of waters in the Little Missouri Basin. Most of the Little Missouri in North Dakota, however, has been designated as a State and recreational river and its flow is thus not available for depletion or, at best, is available for only very limited diversions for future energy and irrigation development.

The expansion of industry will put increasing stress on the existing water resources in the basins, and State planning is underway to assure that minimum stream flows are maintained during low water years, especially in the Little Missouri River in North Dakota. There is presently a particular need for an overall evaluation of water rights and depletions from both basins in all four affected States. Such an inventory would be invaluable in future

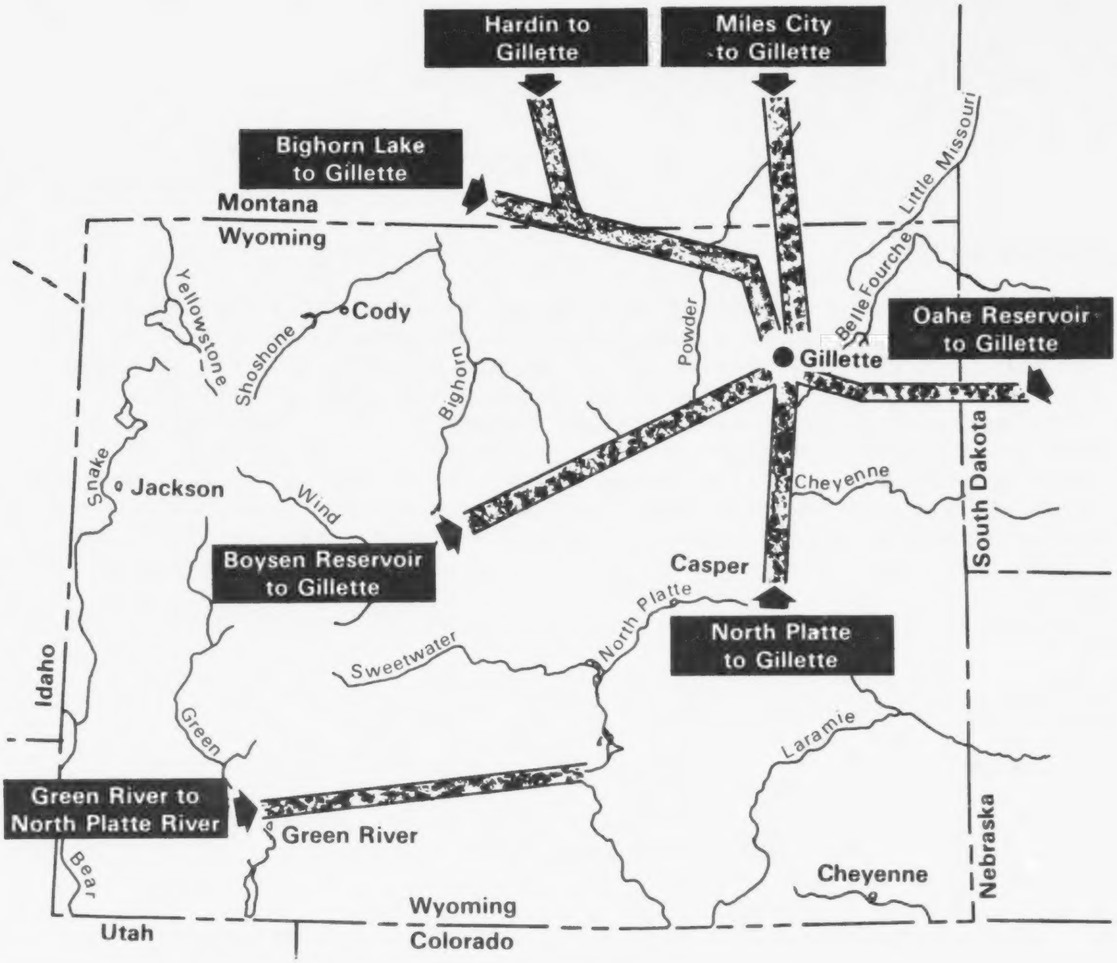

Hardin to Gillette
Miles City to Gillette
Bighorn Lake to Gillette
Montana
Wyoming
Little Missouri
Belle Fourche
Yellowstone
Cody
Shoshone
Powder
Bighorn
Gillette
Oahe Reservoir to Gillette
Snake
Jackson
Wind
Cheyenne
South Dakota
Boysen Reservoir to Gillette
Casper
North Platte
North Platte to Gillette
Sweetwater
Idaho
Green
Laramie
Green River to North Platte River
Green River
Bear
Nebraska
Cheyenne
Wyoming
Utah
Colorado

Figure 12. Proposed alternatives for the importation of water to the Gillette, Wyoming, coal mine development area. (Modified from University of Oklahoma and Radian Corporation 1977a).

decisions regarding allocation of remaining limited surface water resources. The need for water supplies will be felt most acutely during the months of October through February when the area is largely dependent on ground water to supplement reduced surface flows. It is believed that additional storage to regulate the highly unreliable flows of the Belle Fourche and upstream Little Missouri Rivers will be necessary to provide reliable year-round water resources required by the growing energy industry.

8. WATER QUALITY

SOURCES OF DATA

Available water quality information was used to assess the impact of existing energy developments and irrigation projects in the Little Missouri and Belle Fourche River Basins and to provide baseline data for determining the impact of proposed developments. Most of the water quality data contained in this report were obtained through the U.S. Environmental Protection Agency's computer-oriented system for STOrage and RETrieval of water quality data (STORET). Other sources of information include government documents and environmental impact statements. Physical and chemical data evaluated were primarily from U.S. Geological Survey stations (Table 26, Figure 13). Some data collected by miscellaneous sources available in STORET were also considered; however, these data were largely incomplete and provided little supplemental information to the USGS generated STORET data.

SUMMARY OF PHYSICAL AND CHEMICAL DATA

Summarized data for selected parameters are included in Appendix B. These data are organized by parameter, station number, and year for the period 1971-78. Station number assignments in the appendix tables, as well as on figures in this report, are based upon the middle four numerals of the station STORET codes (Table 26).

In Appendix B, data from 7 USGS stations in the Little Missouri River Basin and from 15 USGS stations in the Belle Fourche River Basin are presented. In general, for any given parameter, the annual arithmetic mean for that parameter at each station is presented along with the annual minimum and maximum values and number of samples collected. It should be noted that no attempt was made to verify data retrievals from STORET; all parameter measurements were accepted at face value with the exception of those data that were obviously impossible (e.g., pH = 42) and were thus deleted. No summary tables were prepared from the limited miscellaneous data sources available in STORET for this area.

IMPACT OF DEVELOPMENT ON SURFACE WATER

Salinity

The Salinity Problem--

Salinity, the total concentration of ionic constituents, is a major water quality parameter of concern in the Little Missouri and Belle Fourche River Basins. Two processes contribute to increases in salinity, salt loading and

TABLE 26. U.S. GEOLOGICAL SURVEY WATER QUALITY SAMPLING STATIONS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

STORET Number	Station Description	Latitude	Longitude
Little Missouri River			
06334000	Little Missouri River near Alzada, MT	45° 05' 00"	104° 24' 00"
06334500	Little Missouri River at Camp Crook, SD	45° 32' 49"	103° 58' 23"
06334630	Box Elder Creek at Webster, MT	45° 54' 25"	104° 03' 30"
06335000	Little Beaver Creek near Marmarth, ND	46° 16' 29"	103° 58' 33"
06335500	Little Missouri River at Marmarth, ND	46° 17' 44"	103° 55' 06"
06336000	Little Missouri River at Medora, ND	46° 55' 10"	103° 31' 40"
06337000	Little Missouri River near Watford City, ND	47° 35' 25"	103° 15' 05"
Belle Fourche River			
06425720	Belle Fourche River below Rattlesnake Creek, WY	43° 59' 04"	105° 23' 16"
06425780	Belle Fourche River above Dry Creek near Piney, WY	44° 01' 30"	105° 19' 35"
06425950	Raven Creek near Moorcroft, WY	44° 10' 04"	105° 05' 11"
06426400	Donkey Creek near Moorcroft, WY	44° 16' 58"	105° 03' 48"
06426500	Belle Fourche River below Moorcroft, WY	44° 17' 45"	104° 58' 35"
06427850	Belle Fourche River at Devils Tower, WY	44° 35' 22"	104° 42' 12"
06428500	Belle Fourche River at WY-SD State line	44° 44' 59"	104° 02' 49"
06429500	Cold Springs Creek near Buckhorn, WY	44° 09' 14"	104° 04' 39"
06429900	Sand Creek at Ranch A near Beulah, WY	44° 29' 42"	104° 06' 34"
06430500	Redwater Creek at WY-SD State line	44° 34' 26"	104° 02' 54"
06434500	Inlet Canal near Belle Fourche River, SD	44° 42' 14"	103° 49' 23"
06436700	Indian Creek near Arpan, SD	44° 48' 51"	103° 41' 22"
06436800	Horse Creek near Vale, SD	44° 39' 30"	103° 20' 17"
06437000	Belle Fourche River near Sturgis, SD	44° 30' 47"	103° 08' 11"
06438000	Belle Fourche River near Elm Springs, SD	44° 22' 11"	102° 33' 56"

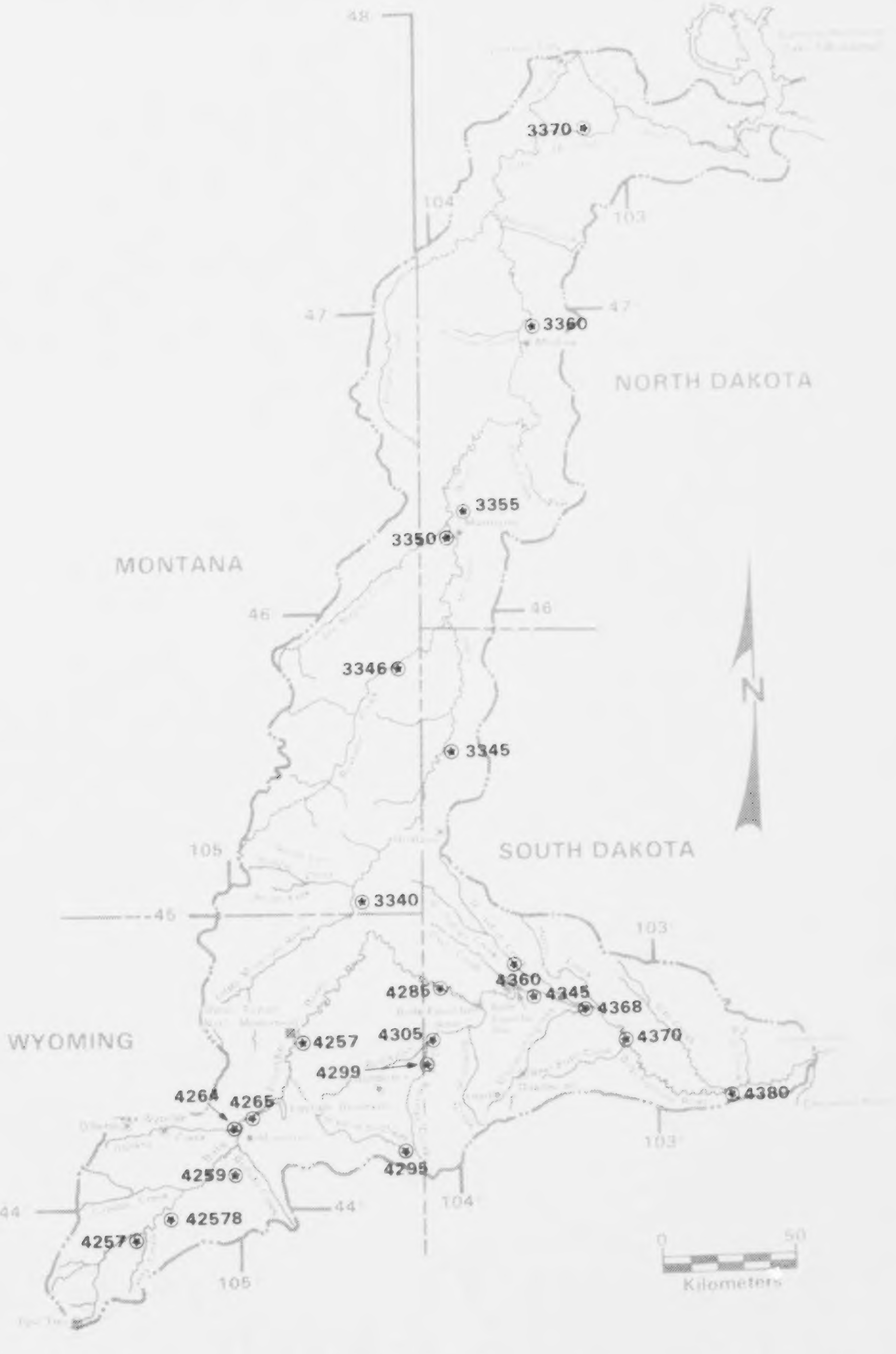

48
3370
104
103
47
3360
NORTH DAKOTA
3355
3350
MONTANA
46
46
3346
N
3345
SOUTH DAKOTA
105
3340
45
103
4360
4286
4345
4368
WYOMING
4257
4305
4370
4299
4264
4265
4380
103
4259
4295
104
44
44
42578
4257
105
0
50
Kilometers

Figure 13. Location of U.S. Geological Survey water quality sampling stations in the Belle Fourche and Little Missouri River Basins.

salt concentrating. Salt loading, the addition of salts to the water system, occurs through irrigation return flows, natural sources, and municipal and industrial wastes. Salt concentrating, reduction of the amount of water available for dilution of the salts already present in the river system, results from consumptive uses of the water and from evaporation and transpiration losses.

Ambient Levels--

Total dissolved solids (TDS) concentrations and conductivity levels provide an indication of the dissolved constituents present in water. Values for these two parameters (Appendix B), as well as concentrations of each of the major cations (calcium, sodium, magnesium, potassium) and anions (bicarbonate, sulfate, chloride) generally increased from upstream to downstream in the Belle Fourche River below Keyhole Reservoir. In the Belle Fourche, surface water samples at Devils Tower, Wyoming, and at Elm Springs, South Dakota, showed an increase in average TDS concentrations from 1126 mg/l to 1809 mg/l, respectively, and an average conductivity increase from 1,470 μmho/cm to 2,200 μmho/cm during 1977 (Table 27). Upstream from Keyhole Reservoir, however, the Belle Fourche River and its supporting tributaries are largely ephemeral. Since intermittent flowing systems can be sampled only during spring runoff and episodic rainstorms, conductivity and salinity measurements for this region are sparse and highly variable.

The Northern Great Plains Resource Program (1974) reports that "the chemical nature of the waters found within the Little Missouri Basin [is] considered to vary as much as the flow and the terrain through which it meanders." This inconsistency in chemical composition can be seen in the STORET data analyzed for this river, and spatial trends of increasing conductivity and salinity levels are not obvious (Table 27).

In the Belle Fourche River below Keyhole Reservoir, calcium is the major cation, followed by sodium, magnesium, and potassium. Upstream from the reservoir, sodium dominates, followed by calcium, magnesium, and potassium. The most abundant anion in the basin is the sulfate ion, followed by bicarbonate and chloride. Throughout the Little Missouri River, water composition was consistently of a sodium sulfate type.

Both the concentrations and composition of dissolved solids in the study tributaries fluctuate with discharge rates. Variation in flow is the major factor accounting for the large seasonal variations in dissolved solid concentrations observed in the basin. Dissolved solids levels tend generally to be high during low runoff times and low during periods of high flow. During summer periods of low runoff, base flow in the rivers is largely from ground-water discharges. Since ground water in this region is generally high in salt content, water quality in the basins seasonally deteriorates during periods of low flow (North Dakota State Water Commission 1975b). The problem is aggravated as a result of the many small natural ponds and livestock impoundments distributed throughout the intermittent upstream Belle Fourche and Little Missouri Rivers. During drought conditions, evaporation rates frequently exceed inflow from ground-water seepage. The resultant periods of zero surface flow produce a series of shallow, disconnected pools in the basins (Northern Great Plains Resource Program 1974). Salt levels in these

TABLE 27. DISTRIBUTION OF MAJOR CATIONS AND ANIONS AT SELECTED STATIONS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS, 1972 AND 1977

Parameter	Little Missouri at Camp Crook		Little Missouri at Marmarth		Little Missouri at Medora		Little Missouri near Watford City		Belle Fourche below Rattlesnake Creek		Belle Fourche at Devils Tower		Belle Fourche at WY-SD State Line		Belle Fourche near Elm Springs	
	1972	1977	1972	1977	1972	1977	1972	1977	1972	1977	1972	1977	1972	1977	1972	1977
Conductivity (µmho/cm)	1867	--	1682	1566	1645	--	1689	1422	--	3175	1448	1470	1716	1726	1726	2200
TDS (mg/l)	1387	--	1415	1062	1250	--	1152	1098	--	1050	1134	1126	1367	1363	2068	1809
Calcium (mg/l)	105	--	67	47	92	--	74	60	--	280	180	176	230	212	236	221
Sodium (mg/l)	269	--	325	260	243	--	247	266	--	310	79	103	89	117	181	174
Magnesium (mg/l)	46	--	46	24	48	--	36	26	--	145	60	54	67	64	113	116
Potassium (mg/l)	11	--	7	9	7	--	8	9	--	12	7	7	8	8	14	15
Bicarbonate (mg/l)	348	--	330	218	316	--	305	300	--	259	227	237	207	204	282	233
Sulfate (mg/l)	761	--	775	590	687	--	613	566	--	1688	679	645	847	845	1137	1135
Chloride (mg/l)	16	--	18	10	7	--	7	9	--	17	6	13	6	12	23	26

ponded areas, as well as in the numerous small livestock ponds in the drainages, frequently increase to the point where established aquatic vegetation can no longer survive (U.S. Geological Survey 1975a). These saline pools are periodically flushed by episodic streamflow events, but during low flows the excessive TDS levels produced are prohibitive to most beneficial uses (North Dakota State Water Commission 1975a).

Sources--

Man's industrial activities increase TDS levels primarily through salt loading processes. Oil field operations in Wyoming are a potential source of substantial salinity impact to the Belle Fourche River Basin below Moorcroft (Missouri River Basin Commission 1978b). At the present time, however, water releases from oil fields in this arid drainage (with TDS concentrations generally less than 3000 mg/l) are not considered a serious water quality threat and are, in fact, often the only source of water available for livestock and wildlife consumption (Wyoming State Engineers Office 1972).

Mining also increases TDS levels through salt loading. Observations of the chemical characteristics of water taken in Donkey Creek below Wyodak, Wyoming (Table 28), reveal that runoff from the mining areas around Gillette contain higher concentrations of dissolved solids than runoff from undisturbed ground (Powder River Areawide Planning Organization 1977). In particular, increases in chloride, sodium, and sulfates over ambient levels observed in the Belle Fourche River reflect the impact of existing mining development in the Gillette area on that drainage. Although data are not available on salinity impact to the study basins from mines in the region other than at Gillette, it is expected that substantial expansion of mining activities will result in significant alterations of water quality in receiving tributaries. However, the impact of mining discharges in this area is highly dependent upon surface discharge levels. During periods of high flow, pumped mine effluents or runoff from tailings piles and receiving ponds are greatly diluted and less severely affect river water quality than in times of low discharge during late summer and fall.

Irrigation activities increase salinity levels in the basins. It is estimated (Northern Great Plains Resource Program 1974) that as much as 60 percent of the total water applied for irrigation may be lost to evapotranspiration. Since this lost water is salt free, the net effect of this concentration can be twofold, or greater, increases in salt levels in the irrigation return flows. Irrigation contributions to salinity through the salt loading process vary with areal soil type, subsurface geology, and use of fertilizers or other agricultural chemicals (Northern Great Plains Resource Program 1974).

Impact--

The EPA water quality criterion for both chlorides and sulfates (Table 29) in domestic water supplies is 250 mg/l (U.S. Environmental Protection Agency 1976b). The sulfate criterion was imposed because of the anion's cathartic effect especially when associated with magnesium and sodium. Chloride levels in excess of the 250 mg/l criterion, particularly in association with calcium and magnesium, tend to produce problems in corrosiveness. Both cations affect water taste when present in

TABLE 28. WATER QUALITY IN DONKEY CREEK, WYOMING, BELOW WYODAK AND NEAR ROZET, JUNE 1975 (Modified from U.S. Geological Survey 1975b)

Parameter	Below Wyodak	Near Rozet
Temperature (°C)	18	18
Conductivity (μmho)	3,000	2,200
Bicarbonate (mg/l)	412	359
Total phosphorus (mg/l)	3.9	1.8
Calcium (mg/l)	210	210
Sodium (mg/l)	400	280
Potassium (mg/l)	24	19
Boron (mg/l)	680	330
Fluoride (mg/l)	1.1	0.8
Total iron (μg/l)	2,100	250
Dissolved iron (μg/l)	80	20
Manganese (μg/l)	460	110
Dissolved oxygen (mg/l)	9.2	7.0
Sulfate (mg/l)	1,500	1,300
Chloride (mg/l)	170	160

concentrations in excess of 300 to 500 mg/l (U.S. Environmental Protection Agency 1976b).

The sulfate criterion has been exceeded between 1971 and 1978 at every USGS station examined in the Little Missouri and Belle Fourche River Basins. In the 1975 water year, the USGS (Briggs and Ficke 1977) reported only 9 streams out of 345 sampled across the Nation, including the Belle Fourche River at Elm Springs, contained mean sulfate concentrations in excess of 1,000 mg/l. Chloride levels were never reported in excess of the EPA drinking water criterion in the Little Missouri-Belle Fourche study area.

TABLE 29. WATER QUALITY CRITERIA RECOMMENDED BY THE NATIONAL ACADEMY OF SCIENCES (1973)*

Parameter (total form)	Criteria for Drinking water (mg/liter)	Livestock (mg/liter)	Aquatic Life (mg/liter)	Irrigation (mg/liter)
Aluminum	--	5.0	--	5.0
Antimony	--	--	--	--
Arsenic	0.05†	0.2	--	0.1 ††
Barium	1.0	--	--	--
Beryllium	--	--	0.011-1.100††	0.1-0.5††
Boron	--	5.0	--	0.75††
Bromine	--	--	--	--
Cadmium	0.01†	0.05	0.0004-0.012††	0.01
Chlorides	250 ††	--	--	--
Chromium	0.05†	1.0	0.1††	0.1
Copper	1.0 ††	0.5	AF	0.2
Cyanide	0.2	--	0.005	--
Dissolved Oxygen	--	--	5.0	--
Fluoride	1.4-2.4†	2.0	--	1.0
Iron	0.3 ††	--	1.0††	5.0
Lead	0.05†	0.05-0.1	0.03	5.0
Lithium	--	--	--	2.5
Manganese	0.05 ††	--	--	0.2
Mercury	0.002 †	0.01	0.05 µg/l††	--
Molybdenum	--	--	--	0.01
Nickel	--	--	AF	0.2
Nitrate nitrogen	10.0 †	100.0	--	--
Nitrite nitrogen	1.0	10.0	--	--
pH	5.0-9.0	--	6.5-9.0	--
Selenium	0.01 †	0.05	--	0.02
Silver	0.05 †	--	--	--
Sulfates	250 ††	--	--	--
Vanadium	--	0.1	--	0.1
Zinc	5.0 ††	25.0	AF	2.0

*Those parameters for which drinking water regulations (1975b) or quality criteria (1976b) have been established by the U.S. Environmental Protection Agency are specially indicated, and in this table replace the older NAS recommended levels.

†U.S. Environmental Protection Agency (1975b)

††U.S. Environmental Protection Agency (1976b)

AF = Application factor; indicates criterion for this parameter must be separately established for each water body.

Tables of water hardness in the study basins are presented in Appendix B. Sawyer's classification of water according to hardness content (U.S. Environmental Protection Agency 1976b) is given in Table 30.

On the whole, streams in the study area are all very hard by this classification. In the Belle Fourche Basin, the station on Cold Creek, Wyoming, is the only site where mean annual values were less than 300 mg/l. This location, however, was only sampled once during 1971-78 and thus is not necessarily representative of annual chemical conditions in the tributary. In the mainstem Belle Fourche, the average annual hardness in the two uppermost stations above Moorcroft, Montana, which are sampled only periodically when flow permits, ranged from 510 to 2,050 mg/l. The three inner stations between Moorcroft and the Wyoming-South Dakota State line ranged from 376 to 927 mg/l, and the two downstream stations in South Dakota ranged from 742 to 1,367 mg/l. In the Little Missouri River Basin, mean

TABLE 30. SAWYER'S CLASSIFICATION OF WATER ACCORDING TO HARDNESS CONTENT (Modified from U.S. Environmental Protection Agency 1976b)

Concentration of $CaCo_3$ (mg/l)	Description
0 - 75	Soft
75 - 150	Moderately hard
150 - 300	Hard
300 and up	Very hard

annual hardness values fell within the hard and very-hard categories. It should be noted that these hardness classifications are based on mean annual values, but within a given stream there are frequently large variations in hardness content across time. This variability is most likely associated with changes in ion dominance resulting from periods of high runoff.

High salinity concentrations and hard water have several adverse effects on municipal needs aside from lowering drinking water quality. If water softening is not practiced, soap and detergent consumption increases, resulting in increased nutrients and other environmental pollution and higher treatment costs in the community. Where water softening is practiced, treatment costs rise with the degree of hardness. Dissolved solids and hardness also play a role in corrosion, scaling of metal water pipes and heaters, and acceleration of fabric wear (U.S. Environmental Protection Agency 1976b).

Description of the impact of total dissolved solid concentrations on irrigation waters in arid and semiarid areas is presented in Table 31 (U.S. Environmental Protection Agency 1976b). Mean annual TDS values for Cold Spring Creek and Sand Creek, and occasionally at Donkey Creek and in the Little Missouri River at Marmarth, North Dakota, have not been in excess of the 500 mg/l limit for the time period 1971-78. Mean annual TDS levels in excess of 2,000 mg/l, i.e., that can be used only for tolerant plants on permeable soils, have been reported in the Belle Fourche River below Rattlesnake Creek, near Piney, Wyoming, at Elm Springs, South Dakota, and in Horse Creek near Vale, South Dakota. However, information at the uppermost Wyoming stations in the Belle Fourche River is based on limited data because of the intermittent nature of the river above Keyhole Reservoir.

Excessive salinity in irrigation water reduces crop yields, limits the types of crops grown in an area, and can affect soil structure, permeability,

TABLE 31. TOTAL DISSOLVED SOLIDS HAZARD FOR IRRIGATION WATER (mg/l)
(Modified from U.S. Environmental Protection Agency 1976b)

Description	TDS
Water from which no detrimental effects will usually be noticed	500
Water that can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants in permeable soils with careful management practices	2,000-5,000

and aeration. Salt adversely impacts plants primarily by decreasing osmotic action and thereby reducing water uptake. The effects of salinity on irrigation are determined not only by the total amount of dissolved solids present but also by the individual ionic composition of the water (Utah State University 1975). Certain plants are sensitive to high concentrations of sulfates and chlorides. Large amounts of calcium can inhibit potassium uptake. Sodium causes plant damage at high concentrations because it increases osmotic pressure and is toxic to some metabolic processes. It can also affect soils adversely by breaking down granular structure, decreasing permeability, and increasing pH values to those of alkaline soils. In 1954 the U.S. Salinity Laboratory proposed that the sodium hazard in irrigation water be expressed as the sodium absorption ratio (SAR),

$$\text{SAR} = \text{Na} / \sqrt{\tfrac{1}{2}(\text{Ca} + \text{Mg})}$$

where Na, Ca, and Mg are expressed as concentrations in milliequivalents per liter of water (McKee and Wolf 1963).

Sodium levels are moderate to high thoughout much of the study area. The National Academy of Sciences (1973) suggested 270 mg/l as the maximum recommended sodium level in drinking water supplies. Between 1971 and 1978, mean sodium levels exceeded this recommended level in many of the tributaries in the study area, including all of the stations in the Little Missouri River Basin except at the mainstem river at Camp Crook, South Dakota. In the Belle Fourche Basin, excessive mean annual sodium concentrations were reported in Horse Creek, Donkey Creek, Raven Creek, and the mainstem Belle Fourche River below Rattlesnake Creek, near Piney, and below Moorcroft. Sodium absorption ratios are generally low throughout the basins: the maximum value reported in STORET at the USGS stations was SAR = 16, which is considered within the usable range for general crops and forages (U.S. Environmental Protection

Agency 1976b). However, the Missouri River Basin Commission (1978a) reports SAR levels do exceed acceptable limits for irrigation in the Little Missouri River during periods of low flow when the discharge is comprised almost entirely of ground-water releases.

Throughout many of the intermittent flowing tributaries in the study basins, water is used almost exclusively for stock-watering purposes. Total dissolved solid concentrations in the basins are not generally restrictive to livestock (Table 32).

TABLE 32. TOTAL DISSOLVED SOLIDS HAZARD FOR WATER USED BY LIVESTOCK (mg/l) (Modified from National Academy of Sciences 1973)

TDS Content in Water (mg/l)	Comment
<1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to these salt levels or watery droppings in poultry.
3,000-4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to these salt levels. Poor water for poultry, often causing watery feces, increased mortality, and decreased growth, especially in turkeys.
5,000-6,999	Can be used with reasonable safety for dairy and beef cattle and for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
>10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Industrial users may be severely affected through use of water that is high in total dissolved solids for cooling or washing purposes. Such water may result in corrosion and encrustation of the metallic surfaces of pipes, condensers, or other machinery parts. However, industrial requirements for purity of water vary considerably (Table 33). Examination of TDS levels throughout most of the Little Missouri and Belle Fourche River Basins (Appendix B) indicates that most industrial needs could be met in those areas without any water treatment efforts. However, at the downstream Belle Fourche stations near Sturgis and in Elm Springs, Horse Creek, and the Belle Fourche River below Moorcroft, mean annual TDS levels tend to be in excess of 1,500 mg/l and some form of deionization would be required for some industrial uses. This factor could be limiting to future industrial advancement in these regions of the study basins.

TABLE 33. MAXIMUM TOTAL DISSOLVED SOLIDS CONCENTRATIONS OF SURFACE WATERS RECOMMENDED FOR USE AS SOURCES FOR INDUSTRIAL WATER SUPPLIES (Modified from U.S. Environmental Protection Agency 1976b)

Industry/Use	Maximum Concentration (mg/l)
Textile	150
Pulp and paper	1,080
Chemical	2,500
Petroleum	3,500
Primary metals	1,500
Copper mining	2,100
Boiler makeup	35,000

The impact of salinity on fish and wildlife is highly variable. Many fish, for example, tolerate a wide range of total dissolved solid concentrations; the whitefish can reportedly survive in waters containing TDS levels as high as 15,000 mg/l, and the stickleback can survive in concentrations up to 20,000 mg/l (U.S. Environmental Protection Agency 1976b). Reproduction and growth may be significantly affected during stress periods, however. The U.S. Environmental Protection Agency (1976b) reports that generally water systems with TDS levels in excess of 15,000 mg/l are unsuitable for most freshwater fish. In the Little Missouri and Belle Fourche River Basins, TDS levels are well below this recommended maximum figure.

Toxic Substances

Trace Elements--

The primary sources of trace elements in the Little Missouri and Belle Fourche watersheds are mine drainage and surface runoff following thunderstorms. A major problem area is Whitewood Creek in the Belle Fourche Basin where pollution from the Homestake Mining Company is responsible for high concentrations of trace elements (Riis 1977).

Energy development may influence trace element levels in several ways. Reduction of water quantity from energy developments and irrigation projects may result in increased trace element concentrations in the basin waters. Additional trace elements, particularly iron, aluminum, manganese, cobalt, nickel, and zinc, may be added to the river through runoff from strip mine tailings and coal storage (Wewerka et al. 1976) or through erosion of soils in disrupted areas. The South Dakota Department of Natural Resources (Riis 1977) reports that pollution from the Homestake Gold Mine produces elevated mercury, cyanide, and arsenic levels in Whitewood Creek and the Belle Fourche River downstream from the mine. Pollution impact is reportedly so severe that Whitewood Creek below the mine cannot support any beneficial uses (Riis 1977), and the natural aquatic fauna of the stream has been completely eliminated (U.S. Environmental Protection Agency 1971a). Indirect runoff of effluents released from evaporative ponds to ground water or through overflow during storms also poses a significant potential water quality threat. Buried deposits of mine tailings, such as occur along the Belle Fourche below Homestake Mine, leach out and contaminate local ground-water supplies (U.S. Environmental Protection Agency 1971a). Finally, trace elements in stack emissions from existing and future coal-fired powerplants, particularly copper, mercury, cadmium, zinc, lead, arsenic, and selenium may be deposited in the drainage basins and can then reach the river through runoff (Northern Great Plains Resource Program 1974).

Total mercury concentrations in USGS surface water samples from 1970 to 1978 exceeded the EPA's recommended criterion for aquatic life (Table 29) in the Little Missouri River near Watford City and in all seven of the mainstem Belle Fourche stations between the headwaters and its confluence with the Cheyenne River. Maximum concentrations were highest in the Belle Fourche River near Elm Springs (9.3 µg/l) and near Sturgis (1.3 µg/l) and in the Little Missouri River near Watford City (1.2 µg/l). Dissolved mercury concentrations exceeding the criterion have been reported in the Little Missouri River near Marmarth and in the Belle Fourche Basin at the Inlet Canal and Horse Creek sites. The U.S. Environmental Protection Agency (1976b) aquatic life criterion of 0.05 µg/l for mercury in water was established to insure safe levels in edible fish; the Belle Fourche station near Elm Springs was also in excess of recommended EPA criteria for mercury levels in drinking water. The U.S. Environmental Protection Agency (1971a) reported that flesh samples from carp in Redwater River (Belle Fourche Basin) contained mercury levels in excess of the recommended Federal Drug Administration standard of 0.5 ppm (µg/g). Those beneficial uses impacted by mercury and other trace element total levels in excess of recommended criteria throughout the Little Missouri and Belle Fourche River Basins are presented in Table 34.

The excessively high mercury levels observed in the Belle Fourche River near Elm Springs probably represent the most harmful pollutant being discharged into Whitewood Creek from the Homestake Mine. Although Homestake Mine discontinued the use of mercury in its milling process in 1970 (U.S. Environmental Protection Agency 1971a), plant effluents still contain

TABLE 34. PARAMETERS EXCEEDING U.S. ENVIRONMENTAL PROTECTION AGENCY (1976b) OR NATIONAL ACADEMY OF SCIENCES (1973) WATER QUALITY CRITERIA, 1970-78, AT U.S. GEOLOGICAL SURVEY STATIONS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Station Number*	Sulfate	Manganese	Iron	Cadmium**	Lead**	Mercury	Aluminum	Dissolved Oxygen	Cyanide	Arsenic
Little Missouri										
3340	DW									
3345	DW									
3346	DW	DW								
3350	DW	DW,I	DW							
3355	DW	DW,I	DW,AL,I			AL				
3360	DW	DW								
3370	DW	DW,I	DW,AL,I	DW,I	DW,AL,L	AL	L,I	AL		DW,L,I
Belle Fourche										
4257	DW	DW,I	DW,AL,	DW,AL,I	DW,AL,L	AL				
42578	DW	DW,I	DW,AL,I	DW,AL,I	DW,AL,L	AL	L,I	AL		
4259	DW									
4264	DW	DW,I								
4265	DW	DW,I	DW,AL,I	DW,I	DW,AL,L	AL	L,I	AL		
4278	DW	DW,I	DW,AL	DW,I	DW,AL,L	AL				
4285	DW	DW,I	DW,AL,I	DW,I	DW,AL,L	AL			AL	
4305	DW									
4345	DW					AL				
4367	DW									
4368	DW					AL				
4370	DW					AL			DW,AL	DW,I
4380	DW	DW,I	DW,AL,I	DW,I	DW,AL,L	AL			AL	DW,L,I

	Chromium	Copper	Nickel	Fluoride	Selenium	Molybdenum	Boron
3346							I
3350				I			I
3355						I	I
3370	DW,AL,I	L,I	I	DW,L,I	DW		
4380	DW,AL,I	I			DW		

---

*For full station descriptions, see Table 26. Beneficial use codes are designated as follows: AL=aquatic life, DW=drinking water, L=livestock, I=irrigation.

**Many observed concentrations are below detection range; minimum detection valuse, however, exceed indicated criteria.

some mercury as a result of leaching out from the ore fed to the Homestake Mill. Furthermore, the South Dakota Department of Natural Resources (Riis 1977) reports that regardless of attempts to eliminate future mining discharges, mercury contamination will continue to be a problem because of high concentrations accumulated in the bottom sediments of Whitewood Creek and the Belle Fourche River downstream.

In 1975, the U.S. Environmental Protection Agency (1975a) evaluated the then-proposed National Pollution Discharge Elimination System (NPDES) permit limitations for mercury and other trace element discharges from the Homestake Mine. Revised permit restrictions were recommended by the EPA at this time to assure the protection of a cold-water fishery in Whitewood Creek, and in 1976 new permit limitations were implemented (Table 35).

TABLE 35. RECOMMENDED REVISIONS OF 1975 NPDES PERMIT LIMITATIONS FOR TRACE ELEMENT DISCHARGES FROM THE HOMESTAKE MINE (Robert Hagen, EPA, Denver, Colorado, Personal communication, 1979)

Element	Proposed Maximum Discharge Value (μg/l)
Cadmium	0.25
Copper	9.00
Zinc	20.00
Chromium	850.00
Lead	280.00
Mercury	1.00
Nickel	1250.00
Silver	1.00
Arsenic	380.00
Cyanide	20.00

Concentrations of iron in the study area are highly variable. Nevertheless, between 1970 and 1978 total iron levels were reported in excess of the recommended criteria for drinking water and aquatic life at all of the mainstem Belle Fourche stations, except near Sturgis, and in the Little Missouri River near Watford. Dissolved iron concentrations exceeding the criteria have been reported at Little Beaver Creek (600 μg/l) and in the Little Missouri River at Marmarth (5700 μg/l). The EPA drinking water criterion for iron was established to prevent objectionable taste and laundry staining (U.S. Environmental Protection Agency 1976b). Iron levels in the Little Missouri River at Watford and in the Belle Fourche near Piney, below Moorcroft, at the Wyoming-South Dakota State line, and near Elm Springs also periodically exceeded the recommended criterion for irrigation waters. In particular, iron reached tremendously high concentrations at the Belle Fourche station near Elm Springs (maximum total value = 740,000 μg/l).

Extremely high concentrations of iron can be fatal to aquatic organisms. Mine drainage, ground water, and industrial wastes are major sources of iron pollution. In the Belle Fourche Basin, tailings from several bog-iron mines throughout the drainage area contribute to violations of recommended criteria for iron (Riis 1977).

Manganese concentrations were also highly variable and frequently exceeded the recommended criteria for irrigation and domestic water supplies at all the mainstem Belle Fourche River stations, at Donkey Creek, at the Little Missouri River sites near Medora and Watford City, and at Little Beaver Creek near Marmarth, North Dakota. High dissolved manganese concentrations, with maximum values ranging from 60 to 1,200 µg/l, have been reported in Box Elder Creek, Little Beaver Creek, and the Little Missouri River at Marmarth and Medora. The 50.0 µg/l criterion for drinking water was established by the EPA to minimize staining of laundry and objectionable taste effects. These undesirable qualities of manganese may increase in combination with even low concentrations of iron (U.S. Environmental Protection Agency 1976b).

Lead was reported at levels in "excess" of recommended drinking water, aquatic life, and livestock criteria throughout the mainstem Belle Fourche River and in the Little Missouri River near Watford City. However, there are problems in interpretation of much of the data on total lead as a result of interferences in analytical methods. In many cases, data points are reported as "known to be less than 100." Since the EPA criteria for drinking water, aquatic life, and livestock are under this minimum detection value, it is impossible to determine in those cases whether recommended limits have been exceeded or not.

Cadmium values equal to or in excess of criteria for aquatic life, drinking water and irrigation were frequently reported at the same stations that reported high lead levels. Maximum concentrations of several trace elements and salts, including nickel, fluoride, selenium, cyanide, arsenic, chromium, and copper, were occasionally in excess of recommended levels in the Little Missouri River at Watford City and in the Belle Fourche River near Sturgis and Elm Springs. The latter two stations, situated below the confluence of the Belle Fourche River with Whitewood Creek, at times contained tremendously high total concentrations of arsenic (maximum value = 22,000 µg/l) and cyanide (maximum = 200 µg/l) during the 1970-78 study period. During 1975, the USGS reported dissolved and total arsenic concentrations were higher in the Belle Fourche River at Elm Springs than at any station in their entire National Stream Quality Accounting Network (Briggs and Ficke 1977).

Aluminum levels periodically exceeded livestock and irrigation criteria in the Little Missouri River near Watford City, in Raven Creek, and in the Belle Fourche River near Piney. Dissolved concentrations of molybdenum and boron have periodically exceeded irrigation criteria in the Little Missouri Basin in Box Elder Creek, Little Beaver Creek, and the Little Missouri River at Marmarth. A complete listing showing the number of times parameters in total form exceeded recommended criteria at USGS stations throughout the study area, as well as the maximum value observed for these parameters, is included in Appendix C.

Pesticides--

Data on pesticides in the study area are limited. Samples have been collected by the USGS in the Belle Fourche River near Elm Springs, at the Wyoming-South Dakota State line, and in the Little Missouri River near Watford City. Maximum values of dieldrin have exceeded the EPA criterion established for freshwater aquatic life in the Belle Fourche River at the Wyoming-South Dakota State line; the 0.003 μg/l standard was proposed by the EPA to prevent hazardous levels of dieldrin bioaccumulation in aquatic organisms used for human food (U.S. Environmental Protection Agency 1976b). Maximum lindane levels that are equal to the recommended criterion for aquatic life have been reported in the Little Missouri River at Watford City. However, data for both Belle Fourche River stations date back to the late 1960's and early 1970's. An update of information from the Belle Fourche River, and an expansion of stations being tested in both river basins, is needed before an accurate evaluation of conditions can be made. However, it might be expected that additional pesticides will be contributed to the river system as a result of expanding irrigation activities.

Radioactive Substances--

Radioactive elements are being monitored by the USGS at only two stations in the study area: the Belle Fourche River above Dry Creek near Piney and at Raven Creek near Moorcroft. Based upon these limited data, it appears that radioactive elements are not a problem in surface waters of this region, since concentrations are below the U.S. Environmental Protection Agency (1976a) Drinking Water Regulations for radionuclides (Table 36). However, more data are necessary before a reliable assessment of radioactivity levels in the Little Missouri and Belle Fourche River Basins can be made.

TABLE 36. U.S. ENVIRONMENTAL PROTECTION AGENCY DRINKING WATER REGULATIONS FOR SELECTED RADIONUCLIDES (Modified from U.S. Environmental Protection Agency 1976a)

Radionuclide	Allowable Level* (pCi/l)
Tritium (H_3)	20,000
Strontium-90	8
Radium-226,228 (combined)	5
Gross alpha (excluding radon and uranium)	15

*No specific limits for allowable concentrations have been set for radionuclides not shown on this table. For these, it is merely specified that their combined dose should not exceed 4 mrem per year to the whole body or to any internal organ.

Suspended Sediments

Suspended sediments are those organic and mineral materials that are released to a watershed from a combination of channel erosion and overland runoff and that are maintained in suspension by turbulent currents or through colloidal suspension. During periods of high flow, bank erosion is escalated and the greater water velocities provide increased energy for scouring and transport of sediments. Many inorganic elements such as trace metals are absorbed and adsorbed onto moving sediment particles making suspended sediments an important transport mechanism. Sediment levels are also important because of their potential impact on light penetration, water temperature and chemical solubility, and aquatic biota (such as abrasive action on aquatic life or the elimination of benthic habitats and spawning areas by settleable solids that blanket the streambeds). In the Belle Fourche and Little Missouri River Basins, suspended sediment data are relatively sparse (Appendix B) and concentrations appear to vary substantially from drainage to drainage.

Suspended sediments are reported to be the primary water pollution problem in the Black Hills and prairie regions of the Belle Fourche River Basin (Riis 1977). Interference with fish reproduction through silting-in of gravel spawning beds is a sediment-related problem of particular concern in the Belle Fourche area (Riis 1977).

In the Little Missouri River, suspended sediment concentrations are highly variable because of the great fluctuations in flow. Nevertheless, during periods of high runoff large amounts of silt from surface erosion are deposited throughout the river streambed. The mean annual suspended sediment discharge in the Little Missouri River at Marmarth is 112 thousand $kg/km^2/yr$ as opposed to an annual discharge of only 50 thousand $kg/km^2/yr$ at Alzada (South Dakota Department of Natural Resources 1972). This high sediment load has a particular impact on Garrison Reservoir; silt deposits from 1.2 to 6.1 m deep have been recorded in the lower 64 km of the Little Missouri River behind Garrison Dam (Northern Great Plains Resource Program 1974).

Nutrients

Nutrient levels in the study area are generally low except during periods of high runoff from snowmelt and storms. In the Little Missouri River Basin, high phosphorus levels reported at Medora can be primarily attributed to agricultural and rangeland-related nonpoint runoff (Missouri River Basin Commission 1978b). In the Belle Fourche Basin, however, there exist several point source problem areas. Donkey Creek is a naturally ephemeral stream that now flows perennially as a result of sewage discharges from the community of Gillette, Wyoming (U.S. Department of Interior 1974). Whitewood Creek in South Dakota is also impacted by raw sewage discharges from the towns of Lead and Deadwood (Riis 1977).

The embayment of Garrison Reservoir (Lake Sakakawea) to which the Little Missouri River discharges has been classified as mesotrophic by the U.S. Environmental Protection Agency (1976c). In that study, total phosphorus levels from 45 to 500 μg/l were recorded in the Little Missouri River at

Garrison Reservoir during the 1974-75 water year. Keyhole Reservoir, on the Belle Fourche River below Donkey Creek, has been classified by the U.S. Environmental Protection Agency (1977b) as eutrophic. Of the 14 Wyoming lakes sampled in 1975 by the National Eutrophication Survey, 4 had lower median total phosphorus concentrations than Keyhole Reservoir.

Since agricultural runoff and sewage are the major sources of nutrient loadings to this area, any future irrigation projects could contribute additional nutrients to basin waters. Increased sewage and urban runoff, a result of the expected population expansion from proposed irrigation projects and energy developments, could further increase nutrient concentrations in the rivers if not carefully controlled.

Temperature

Temperature is a parameter of significance to the stability of aquatic systems. It controls the geographical dispersal of biotic communities, is related to ambient concentrations of dissolved gases, and affects the distribution of chemical solutes in lentic water bodies through the phenomenon of stratification. Of particular interest in the Belle Fourche River are variations in temperature as they relate to fisheries of the area. Changes from a cold-water to a warm-water fishery occur if temperatures are directly lethal to adults or fry, cause a reduction in activity, or limit reproduction (U.S. Environmental Protection Agency 1976b). There are major trout hatcheries on Spearfish Creek and Redwater River in the Belle Fourche Basin that could be affected by large-scale temperature increases. However, most streams in the Belle Fourche drainage area are intermittent, with elevated water temperatures, and are not suitable for maintenance of a cold-water fishery.

In general, raw data trends for temperature in the study basins indicate that water temperature is highest in July, August, and September and lowest in December, January, and February. However, water temperatures in the Little Missouri River Basin are highly variable (Appendix B) and subject to rapid change particularly in the summer months. Elevated temperatures in the river become a problem in the unprotected shallow pools that form as surface flows are reduced.

Dissolved Oxygen

Waters in the Little Missouri and Belle Fourche River Basins study region are generally well aerated (Appendix B). The dissolved oxygen minimum established by the U.S. Environmental Protection Agency (1976b) for maintaining healthy fish populations is 5.0 mg/l. Dissolved oxygen levels from 1970 to 1978 at the USGS stations dropped below this level in three creeks of the study area including the Little Missouri River near Watford City (3.8 mg/l minimum value), Belle Fourche River above Dry Creek near Piney (4.3 mg/l minimum), and the Belle Fourche River below Moorcroft (4.7 mg/l minimum). For these three sampling sites, dissolved oxygen concentrations below the water quality standard were reported only in December and January and most likely reflect times of ice cover. Values below 5.0 mg/l have also been noted in the hypolimnion of Garrison and Keyhole Reservoirs during the summer and early fall stratification periods.

It should be noted that dissolved oxygen was not measured at most of the tributaries in the Little Missouri-Belle Fourche study area, and it is likely that low oxygen conditions do occur seasonally at locations in the basins other than the sites mentioned above. Riis (1977) reports oxygen depletions also occur in Whitewood Creek below the communities of Lead and Deadwood where raw sewage is discharged.

pH and Alkalinity

The ionic composition of water and, therefore, biological systems are affected by pH. Waters in the study area are basically alkaline with pH values usually between 7 and 9 (Appendix B). The only exceptions to this range were a few stations in the Little Missouri and Belle Fourche Basins where minimum pH levels occasionally reached 6.6 to 6.9 and in the Belle Fourche River at Elm Springs where a maximum value of 10.2 was reported.

Alkalinity is a measure of the ability of water to resist change in pH as a result of the addition of acids. It is influenced primarily by carbonate and bicarbonate but may also be affected by phosphates, hydroxides, and other substances to a lesser degree (Briggs and Ficke 1977). Waters in the study area are well buffered, and mean alkalinity values were greater than 100 mg/l throughout both basins. In general, alkalinity mean values in the Little Missouri River (Appendix B) were much higher than in the Belle Fourche Basin. However, data from USGS stations in the Little Missouri Basin are much less complete than in the Belle Fourche drainage, and this apparent difference in chemical composition most probably reflects the inconsistency of sampling frequencies between the two basins.

IMPACT OF DEVELOPMENT ON GROUND WATER

Ambient Levels

Ground water in the shallow sandstone and alluvial aquifers along major streams in the Northern Great Plains area is of fair to poor quality because of high concentrations of dissolved solids. The Missouri River Basin Commission (1978b) indicates that mean TDS concentrations of 1,000 to 5,000 mg/l are typical for water from the shallow aquifers in northeastern Wyoming. Water of this salinity is generally considered of marginal or unsuitable quality for human consumption. However, in the Little Missouri and Belle Fourche River Basins the chemical quality of ground water is a factor that must be considered in coordination with an evaluation of the supply. Although ground-water resources in this region have most commonly been used for stock and domestic purposes, many people in the study area drink water with TDS concentrations in excess of 1,000 mg/l because nothing else is available (Wyoming State Engineers Office 1973). In the more arid plains regions of the basins, where surface water supplies are largely intermittent, ground water is considered the single most important natural resource.

Local ground-water quality variations (Table 37) result from differences in water sources and soil permeability (Northern Great Plains Resource Program 1974). The more shallow alluvial aquifers respond more rapidly to contamination of surface and near-surface waters than do the deeper bedrock

TABLE 37. A PARTIAL LISTING OF GROUND-WATER SOURCES IN NORTHEASTERN WYOMING
(Modified from Wyoming State Engineers Office 1973)

Geologic Period	Aquifer/Formation		Depth Range of Wells (m)	TDS Range (mg/l)
Quarternary	Sand and gravel	(unconsolidated)	3 - 30	106 - 3,340
Tertiary	Wasatch	(sandstone)	12 - 305	160 - 6,620
	Fort Union	(sandstone)	46 - 183	484 - 3,250
Cretaceous	Lance	(sandstone)	46 - 366	450 - 3,060
	Fox Hills	(sandstone)	61 - 701	1,240 - 3,290
	Mesaverde	(sandstone)	12 - 914	550 - 34,793*
	Cody	(sandstone)	30 - 335	6,392 - 12,580
	Frontier	(sandstone)	21 - 610	390 - 25,000*
	Cloverly or Inyan Kara or Lakota or Dakota		76 - 1,829	218 - 18,706*
Jurassic	Sundance	(sandstone)	122 - 213	894 - 2,310
Triassic	Spearfish	(sandstone)	6 - 274	2,590
Pennsylvanian	Tensleep/Amsden or Casper or Minneluska		73 - 1,981	255 - 200,000*
Ordovician	Bighorn		0 - 61	427 - 3,219*
Cambrian	Flathead		20 - 1,798	124 - 18,634*
Precambrian	Granite		<1 - 5	63

*Values from oil test waters

(consolidated materials) aquifers. Water in the deeper aquifers, however, deteriorates with increasing depth as a result of gradual leaching of ions through the formation (Northern Great Plains Resource Program 1974). Since only limited data are available from wells in the study area, a complete, reliable water quality appraisal of the area is not possible at this time. The variability in quality of principal ground-water aquifers in the study area, however, is shown in Table 38. It appears that the range of TDS values for the shallow aquifers is characteristic of shallow bedrock and alluvial aquifers (Missouri River Basin Commission 1978b). The chemical quality of water in the deeper Minneluska aquifer (found at depths greater than 1,500 m) is more variable; nevertheless, its mean TDS values of 22,000 mg/l and conductivity from 10,000 to 20,000 μmho/cm (Missouri River Basin Commission 1978a) reflect its generally brackish nature. A more complete presentation of the availability and quality of ground water in the Little Missouri and Belle Fourche River Basins in northeastern Wyoming is presented on Table 39.

Man's Impact

Water quality problems associated with mining include acidity, increased salt content, higher heavy metal concentrations, and greater sediment loads (Warner 1974). Mines remain pollution sources even after closure, further complicating pollution control.

The current and proposed mining developments in the Little Missouri and Belle Fourche River Basins could impact ground water in several ways. The removal of overburden during mining and its replacement for land reclamation expose additional minerals to oxidation and solution with resultant deterioration of ground-water quality (Missouri River Basin Commission 1978b). One problem is contamination of ground water by infiltration from mining operations. This effect could ultimately impact nearby intermittent streams since water that infiltrates through the spoils materials into shallow aquifers eventually emerges as ground-water discharges into streams. The chemical composition of the coalbed, overlying rock strata, and surrounding soil types all greatly influence the nature and extent of ground-water contamination (Harza Engineering Company 1976). A second problem involves disturbance of saline and sodium-rich soils in the study area to a sufficient degree that leaching of salts to the ground-water aquifers is substantially increased. Road construction is a secondary impact related to mining activities that has particularly contributed to surface disturbance and resultant salinity problems in the mine-sensitive soils of eastern Montana and Wyoming (North Great Plains Resource Program 1974).

TABLE 38. CHEMICAL CHARACTERISTICS OF A NUMBER OF GROUND-WATER AQUIFERS IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS, WYOMING AND SOUTH DAKOTA (Modified from Wyoming State Engineers Office 1972, and Riis 1977)

Formation Type	#of Samples	Mean Parameter Concentrations (mg/l)												
		Silica	Iron	Manganese	Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulfate	Chloride	Fluoride	Boron	TDS
Alluvium	16	16	2.1	0.5	134	48	230	9	398	646	19	0.4	0.3	1,352
Wasatch	17	12	2.1	0.1	124	87	255	6	457	783	13	0.6	0.2	1,630
Fort Union	19	9	1.6	0.03	75	31	421	6	894	453	18	1.3	0.1	1,483
Lance	12	12	1.8	0.1	99	30	402	4	612	673	30	0.9	0.2	1,618
Fox Hills	4	10	0.2	--	29	13	654	4	749	958	191	0.4	0.4	2,432
Inyan Kara	28	9	1.3	0.1	58	19	168	5	922	328	1,388	0.4	0.2	3,592
Minneluska	25	8	0.3	--	648	178	14	8	377	2,330	11,518	2.0	0.1	22,621
Pahasapa	4	12	0.03	--	226	34	19	4	216	446	116	0.4	0.1	988
Dakota		19	30	10	8	3	1,800	8	1,500	19	1,900	2.4	6,600	4,510

TABLE 39. AVAILABILITY AND QUALITY OF GROUND WATER BY BASIN AND TIME-ROCK UNIT IN NORTHEASTERN WYOMING (Modified from Wyoming State Engineers Office 1972)

Quarternary Aquifers	Tertiary Aquifers	Pre-Tertiary Aquifers
LITTLE MISSOURI RIVER DRAINAGE AREA (POWDER RIVER BASIN-EAST)		
Flood plain alluvium of the Little Missouri River and tributaries contains relatively shallow aquifers, and small well yields are reported. The water is very hard, contains relatively high concentrations of iron, and is moderately to highly mineralized. The Little Missouri River flows across the Skull Creek shale in much of the area, which probably influences the mineral content of the ground water in the alluvium.	The Tullock sandstone of the Fort Union Formation is present in a very small part of the study area, along the county line between Campbell and Crook Counties and south of the Little Missouri River. The extremely local presence of this unit and the absence of other Tertiary units implies that the Tertiary is not significant in this area, even though the Tullock does yield water to a few stock and domestic wells. (Note: A small part of the area is in the region of the Black Hills uplift).	In areas where the Lance Formation is exposed (western part of the study area), wells can usually obtain small amounts of water from relatively shallow depths (61 m). Water from the Lance may be soft, but highly mineralized. The Fox Hills sandstone will yield small amounts of water to wells probably of similar quality as found in the Lance. In the valley of the Little Missouri River, wells are drilled 38 to 91^+ m into the Inyan Kara. A high TDS content would be expected. The availability of ground water in older (deeper) aquifers would be similar to the Belle Fourche River drainage area.
BELLE FOURCHE RIVER DRAINAGE AREA (POWDER RIVER BASIN-EAST AND BLACK HILLS UPLIFT)		
Flood plain alluvium yields small supplies to wells. The water is used mostly for stock and domestic purposes, rarely for irrigation. Permeable beds in the alluvium are relatively thin and of small areal extent. Ground water in the alluvium generally is very hard, has a high concentration of iron, and is moderately to highly mineralized. The chemical character of the water differs and is greatly influenced by the bedrock underlying the alluvium.	West of the uplift, the Wasatch Formation yields small to moderate amounts of water to wells from depths of 29 to 104 m. The water has a considerable range of TDS concentration and hardness. Iron is locally found in objectionable quantities. The Fort Union Formation yields water from depths of 152 to 914^+ m. Water quality varies; the water is moderately to highly mineralized and usually (but not always) hard. Iron is present in low concentrations.	Cretaceous and older formations crop out on the uplift and disappear to the west, dipping under the Tertiary cover in the Powder River Basin. Small yields are reported from depths of 46 to 61 m in the Lance Formation near the outcrop. The water is not as highly mineralized as that from the Fort Union. The Fox Hills sandstone yields water to a well in the vicinity of Gillette. The depth of this well is approximately 1067 m. A sample of the water was found to be very soft, to have 1,150 mg/l TDS, and 8 mg/l fluoride. There is a great thickness of shale underlying the Fox Hills, and other aquifers are found some 914 to $1,524^+$ m deeper in the geologic basin. These same aquifers outcrop in the uplift and yield water from relatively shallow depths in the eastern part of the area. Numerous wells have been drilled into the Inyan Kara and yield small amounts of water from depths of 49 to 305 m.

(Continued)

TABLE 39. (Continued)

Quarternary Aquifers	Tertiary Aquifers	Pre-Tertiary Aquifers
		Wells in the valley of the Belle Fourche River commonly flow. Jurassic and Triassic sandstones also yield small amounts of water to wells. Water from the Inyan Kara may contain troublesome amounts of iron. Water from Jurassic and Triassic sandstones commonly are highly mineralized, although water from the Hulett sandstone locally has a low TDS content.
		In the uplift area the Minneluska Formation yields water from depths approaching 213 m. The water is very hard and has a low TDS content. West of the uplift, in the vicinity of Gillette, depth to the aquifer is 2,743 m and the water has a TDS content of 3,000 to 13,000 mg/l.
		The Pahasapa yields large amounts of water to wells, at least locally. A large flowing well reportedly was constructed at Osage, while a well 234 m deep at Sundance was abandoned after penetrating 53 m of Pahasapa. Large yields are obtained from fissured or cavernous limestone. Depth to the limestone is about 366^+ m in the Belle Fourche River valley on the uplift and increases rapidly towards the west and southwest.

9. ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT

IMPACT ON WATER QUANTITY

In the Belle Fourche and Little Missouri River Basins, surface water availability is expected to be a major factor limiting growth and development patterns, including development of energy resources. Surface water supplies in both basins are highly erratic and vary substantially from season to season and from year to year. In the Belle Fourche River, it is estimated that 107 million m^3/yr of water is available for reapportionment. Most of this is presently committed to agricultural users. In the Little Missouri River, there is no known estimate on the quantity of water annually available for consumption by authorized users. Predictable surface flows occur only during the early spring as a result of snowmelt, and virtually all this water is committed to irrigation and stock usage. During the summer months the river becomes essentially a dry bed interspersed with small evaporation ponds.

In the Belle Fourche Basin, the Keyhole and Belle Fourche Reservoirs have tended to normalize the effects of the unpredictable surface flows, but these do not totally eliminate the impact of a drought year on regional surface water resources. Energy development, particularly surface mining and the subsequent conversion of coal into electricity, requires enormous amounts of water. Large quantities of water are also needed for reclamation projects to restore mined areas and for planned transportation of coal out of the vicinity if coal slurry line is used. This fact is significant since many of the streams in the coal-rich area of the Belle Fourche watershed around Gillette, Wyoming, are dry much of the year. In both basins, ground-water supplies play a major role in supplementing surface flows during seasons of low precipitation and, in fact, are the major source of water used by the energy development activities that are already ongoing. However, increases in mining and conversion activities in the basins will prevent this source from providing any large-scale cushion to surface water diversions for an extended period of time and may also impact the quality of shallow aquifers to the point that available water is unacceptable for most beneficial uses.

It is sometimes assumed that all water not otherwise consumed is available for diversion and energy utilization. This attitude overlooks the many ecological needs for the "unused" water: instream flow maintenance for the preservation of critical wetlands and riparian habitats, conservation of the native environment of endangered species, etc. The Little Missouri River in North Dakota has been designated a State scenic and recreational river and the maintenance of instream flows in that area is of particular importance, although the need is complicated by the fact that it is not really known how much water is reliably available in the river from year to year. It is clear that in both basins the development of additional storage facilities, and perhaps diversion of water from the Yellowstone and Bighorn Rivers through aqueducts, will be necessary in the future to assure that sufficient water will be available to meet anticipated energy development, irrigation, and recreational demands.

IMPACT ON WATER QUALITY

Surface water quality in the Belle Fourche and Little Missouri River Basins is highly variable. Tributaries throughout much of the study region are ephemeral, and in these areas water quality is dependent on seasonal variations in the primary source of flow (whether ground water or precipitation) and the quantity of discharge. In general, water quality is adequate for most irrigation, livestock watering, municipal, and industrial needs of the region. There exist, however, geographically localized problem areas, as well as some specific parameters that are of concern throughout the entire study basin.

At present, salinity levels are a major concern to the basins. During low discharge periods, flow in the Little Missouri River and in the Belle Fourche River above Keyhole Reservoir is largely from ground-water discharges that are usually high in salt content. In the Little Missouri River, this saline base flow, combined with high evaporation rates in numerous small ponds created by the intermittent summer discharge, often results in TDS levels that are prohibitive to most beneficial uses. Mining activities around Gillette, as well as Wyoming oil field operations, contribute to elevated salt concentrations, particularly chloride, sodium, and sulfate, in the upper Belle Fourche River. Sodium absorption ratios are commonly reported in excess of acceptable limits for irrigation in the Little Missouri Basin during low flow periods. Frequently these highly saline waters are the only source available for both livestock and human consumption during the low discharge summer months.

Sediment loading is a problem in some parts of the study area, especially in the Black Hills and prairie regions of the Belle Fourche Basin where suspended sediments are considered the primary water pollution problem (Riis 1977). Increases in sediment-related problems can be expected as a result of growing resource development in the Belle Fourche and Little Missouri Basins, particularly around Gillette, Wyoming, where expanded mining activities are expected. Any future industrial and agricultural projects will intensify problems with erosion through construction activities, transport roads, and removal of overburden for mining. In the Belle Fourche Basin, high sediment loading is of special concern because of its impact on fish reproduction; in the Little Missouri Basin, sediment loading is more variable because of the natural flow fluctuations but nevertheless has had a great impact on Garrison Reservoir.

Some increases in nutrient and trace element concentrations can also be expected as a result of flow reductions associated with energy development activities in the study area. Population expansion and accompanying construction could further increase nutrient loading to the rivers if not carefully controlled. Nutrient concentrations, and associated oxygen reduction, are already a problem in Donkey Creek, because of sewage discharges from the energy area of Gillette, and in Whitewood Creek, which receives discharges from the Homestake Gold Mine. Trace element concentrations are also already extremely high in the Belle Fourche River below the Homestake Mine, and increases resulting from mining or coal conversion facilities could have an acute impact on beneficial utilization of that river. The effect of the planned energy developments on temperature, pH, and alkalinity are not expected to be substantial and will, in all probability, be a result of reduced flows or hydrological modifications produced by supplemental reservoir construction.

The quality of ground water in the basins is fair to poor because of high concentrations of dissolved solids. Much of the low-quality water is natural to the basins, with dissolved solids and the major ions leaching into the ground-water systems from the overlying shale. However, energy developments can intensify the problem. In addition to reducing the ground-water levels to supplement variable surface water flows, contamination of the aquifers is possible.

10. RECOMMENDED WATER QUALITY MONITORING PARAMETERS

An objective of water quality monitoring in the Little Missouri and Belle Fourche River Basins should be to assess the impact of energy resource development, irrigation projects, and associated developments. Toward this end a determination of those parameters that will provide meaningful data is needed. In this report, the nature and type of possible pollutants from the major activities in the basins were inventoried. The possible effects of these, as well as those parameters that are already being monitored, were reviewed and a proposed priority list of parameters of interest in the Little Missouri and Belle Fourche River Basins was prepared.

PHYSICAL AND CHEMICAL PARAMETERS

The selection of water quality parameters that should be routinely monitored in the Little Missouri-Belle Fourche study area is not obvious. Physical data provide information on water temperatures, quantities (flow), osmotic pressures (salinity, conductivity), suspended sediment, and other factors that affect both the biota and the chemistry. The utility of these data must be considered when selecting parameters for measurement. Similarly, the ambient level of a chemical, its effect upon the biota, and interactions with other chemicals present must be known if a cost-effective monitoring network is to be implemented.

Knowledge of the substrate composition is also essential to provide a thorough assessment of environmental pollution. Many organic and inorganic pollutants are adsorbed onto sediment particles or organic debris. Other pollutants, such as iron, may form flocculants or precipitates or may sink of their own accord. These materials may be deposited in areas of slow-moving water or left as evaporites in the dry washes of the area. They may, however, be resuspended during periods of erosion or be released as dissolved constituents following a change in environmental conditions. The deposited sediments therefore represent both a pollutant sink and a potential pollution source.

As a means of identifying and setting priorities for those parameters most appropriate for monitoring energy development, each potential pollutant previously addressed is evaluated in terms of the projected impact on ambient water quality with respect to beneficial water use criteria. Also evaluated are those "indicator parameters" that, although not in themselves pollutants, either provide a direct or indirect measurement of environmental disturbances or are required for the interpretation of other water quality data. The following symbols are used for identifying those beneficial water uses affected by existing or projected increases in parameter ambient levels:

Symbol		Beneficial Water Uses
I	=	Irrigation
D	=	Drinking water (public water supplies)
A	=	Aquatic life and wildlife
W	=	Industrial uses
L	=	Livestock drinking

Three priority classifications are developed based on criteria given below. These are:

- Priority I (Must Monitor Parameters), which should be collected regularly at energy development assessment monitoring stations (Table 40).
- Priority II (Major Interest Parameters), which would be desirable to monitor in addition to Priority I parameters if resources permit (Table 41).
- Priority III (Minor Interest Parameters), which are presently being monitored by the existing network but which will provide little useful data for monitoring energy development impacts on water quality in the Little Missouri and Belle Fourche River Basins (Table 42).

This classification represents an attempt to: (1) identify those parameters that will be most effective in monitoring the impact of energy development in the Little Missouri and Belle Fourche River Basins; and (2) permit the detection of increases in parameter levels that may be deleterious to designated beneficial water uses.* This classification scheme is not intended to preclude monitoring of low priority or unmentioned parameters for special studies or for purposes other than assessment of energy development impact. Neither does it require the elimination of those parameters already being collected for baseline data that are very inexpensive to monitor. The priorities do not attempt to address sampling frequency. However, monitoring frequencies are discussed briefly in Section 11 and will be addressed in greater detail in subsequent documents in this energy series.

Parameters for use in the rapid detection of short-duration events such as spills, monitoring for permit discharge purposes, and intensive survey or

---

*All assessments relative to beneficial water uses are based on U.S. Environmental Protection Agency (1976b) criteria or drinking water regulations (U.S. Environmental Protection Agency 1975b). In those cases where EPA established criteria have not presently been defined, National Academy of Science (1973) recommended criteria are used.

TABLE 40. PRIORITY I, MUST MONITOR PARAMETERS FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Parameter†	Primary Reason for Monitoring	Category and Beneficial Water Use Code††
Alkalinity, total (as $CaCO_3$)	Needed for interpretation of water quality data.	1
Aluminum, total	Periodically exceeded recommended criteria for irrigation and livestock in Belle Fourche River above Moorcroft and in Little Missouri River near Watford City.	2I,L
Arsenic, total	Periodically exceeded recommended levels for drinking water, livestock, and irrigation in Belle Fourche River below Whitewood Creek and in Little Missouri River near Watford City. Dissolved values exceeding criteria have been reported in Belle Fourche River near Sturgis; may increase near gasification sites.	2D,I,L; 3D,I,L
Bicarbonate ion	Important anion in the Little Missouri and Belle Fourche Rivers, may be affected by energy development.	4
Biological oxygen demand of sediments, 5 day†	Measure of pollution increases in the basins, sediment serves as an integrative accumulator.	4
Boron, total	Dissolved form exceeded irrigation criterion in Box Elder and Little Beaver Creeks and Little Missouri River at Marmarth.	2I
Cadmium, total	Reported in excess of criteria for drinking water, irrigation, and aquatic life throughout Belle Fourche Basin and in Little Missouri River at Watford City. Levels may increase at future gasification sites.	2A,D,I; 3A,D,I
Carbon, total organic in sediments†	Provides indiction of organic contamination, many elements and compounds are preferentially absorbed into organic debris.	4
Calcium, dissolved	Dominant cation in Belle Fourche River below Keyhole Reservoir, may be affected by energy development.	4
Chloride	Increased levels anticipated from mine spoil drainage.	3D,I
Chromium, total†	Levels reported in excess of drinking water, aquatic life and irrigation criteria in Little Missouri River near Watford City, and Belle Fourche River near Elm Springs.	2A,D,I
Specific conductance, at 25°C	Useful indicator of TDS, affects overall water chemistry.	4

†Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments, unless specified for bottom sediments only.
††For full explanation of category codes, see Section 10.

(Continued)

TABLE 40. (Continued)

Parameter†	Primary Reason for Monitoring	Category and Beneficial Water Use Code
Copper, total	Exceeded irrigation water criterion in Belle Fourche River at Elm Springs, and irrigation and livestock criteria in Little Missouri River near Watford City.	2I,L
Cyanide, total†	Exceeded criterion for aquatic life in Belle Fourche River at WY-SD State line and below Whitewood Creek; exceeded drinking water criterion as well in Belle Fourche near Sturgis. May increase near future gasification sites.	2A,D; 3A,D
Dissolved oxygen	Necessary for maintenance of aquatic life and affects water chemistry; at some stations in study area, levels have been less than the EPA criterion for aquatic life.	1; 2A; 4
Flow	Needed for interpretation of water quality data.	1
Fluoride	Reported in excess of drinking water, livestock, and irrigation criteria in Little Missouri River near Watford City. Dissolved values exceeding irrigation criterion have been reported in Little Beaver Creek.	2D,I,L
Iron, total†	Levels have frequently exceeded recommended criteria for aquatic life, drinking water, and irrigation throughout the study basins, may increase with expanding mining activities.	2A,D,I; 3A,D,I
Lead, total†	Exceeded drinking water, livestock, and aquatic life criteria in both basins. May increase near future gasification sites.	2A,D,L; 3A,D,L
Magnesium, dissolved†	Important cation in study area, may be affected by energy development.	4
Manganese, total	Commonly exceeded criteria for drinking water and irrigation in both basins. May be increased by gasification.	2D,I; 3D,I
Mercury, total†	Frequently exceeded EPA criterion for aquatic life throughout both basins; extremely high value (9.3 μg/l) exceeding drinking water criterion reported in Little Missouri River at Elm Springs. Possible contribution from future powerplants and gasification plants.	2A,D; 3A,D; 4
Molybdenum, total	Dissolved form reported in excess of irrigation water criterion in Little Missouri River at Marmarth.	2I
Nickel, total	Exceeded irrigation criterion in Little Missouri River near Watford City. Could be increased near gasification sites.	2I
Nitrate-nitrite-N	Primary nutrient, expected to increase, could approach health limits in the future.	3D, L
Pesticides	Maximum levels of dieldrin have exceeded EPA criterion for aquatic life in Belle Fourche River at WY-SD State line, maximum lindane levels have exceeded aquatic life criterion in Little Missouri River near Watford City. Increasing agricultural activity may lead to further increases in pesticides/herbicides in the basins.	2A; 3A,D

†Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments.

(Continued)

TABLE 40. (Continued)

Parameter†	Primary Reason for Monitoring	Category and Beneficial Water Use Code
Petroleum hydrocarbons (includes benzine, toluene, oil and grease, napthalene, phenols, olefins, thiophenes, and cresols)	Can be expected to increase throughout the basin.	3A,D
pH	Need for interpretation of water quality data.	1; 4
Phosphorus, total†	Primary nutrient contributing to algae and macrophyte growth, expected to increase.	4
Potassium, dissolved	Important cation in study area, may be affected by energy development.	4
Selenium, total†	Exceeded drinking water criterion in Little Missouri River near Watford City and irrigation criterion as well in Belle Fourche River at Elm Springs. Levels may increase around future coal-fired powerplants from stack emissions.	2D,I; 3D,I
Sodium, dissolved	Major cation in Belle Fourche River above Keyhole Reservoir, increased levels anticipated from mine spoil drainage and increased use of water conditions.	
Sulfate, dissolved	Dominant anion throughout both basins; commonly exceeded EPA criterion for drinking water throughout study area; may be affected by energy development.	2D; 4
Suspended sediments	Major transport mechanism, indicator parameter, expected to increase with energy development.	1; 3A,I; 4
Temperature	Needed for interpretation of water quality data, could increase with development.	1; 3A; 4
Total dissolved solids	Indicator parameter; downstream salinity problems anticipated with increasing irrigation and energy development.	2D,I; 3D,I; 4

†Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments.

TABLE 41. PRIORITY II, PARAMETERS OF MAJOR INTEREST FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Parameter†	Primary Reason for Monitoring	Category and Beneficial Water Use Code††
BOD, 5 day	May provide basic information on increased pollution.	7
COD, low level	May provide an indication of pollution by oxygen consuming substances.	7
Total hardness, $CaCO_3$	Of interest to both industry and public, not a problem at present, but may become so in certain areas as water consumption and irrigation runoff increase.	6D,I,W; 7
Kjeldahl-N, total	Primary nutrient, expected to increase with development.	7
Sediment size distribution	Provides data on stream velocity, stream habitat, sediment sources.	7
Turbidity	Easy to measure, provides quick data about suspended sediment, etc.	7

†Parameters (except for sediment size distribution) are determined in water samples only.
††For full explanation of category codes, see Section 10.

TABLE 42. PRIORITY III, PARAMETERS OF MINOR INTEREST THAT WILL PROVIDE LITTLE USEFUL DATA FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Parameter†	Primary Reason for Monitoring	Category and Beneficial Water Use Code††
Beryllium, total	Recorded values very low (maximum 10 μg/l).	8
Barium, dissolved	Difficult to measure, does not approach critical limits (maximum water sample 300 μg/l, maximum in sediments 800 μg/l).	8
Carbonate	Generally low levels in basins, usually of little significance in alkaline waters. Levels moderate in basins (maximum 300 μg/l), has few adverse effects at high levels.	8
Cobolt, dissolved	Levels moderate in basins (maximum 300 μg/l), has few adverse effects at high levels.	8
Silica	Generally low throughout basins.	8
Gallium, dissolved	Values low (maximum 7 μg/l).	8
Germanium, dissolved	Values low (maximum 40 μg/l).	8
Lithium, total	Values range from low to moderate (maximum 320 μg/l) total form, 300 μg/l dissolved form).	8
Nitrate-N} Nitrate-N}	Monitored simultaneously by NO_2-NO_3. If NO_2- NO_3-N levels begin to approach 10,000 μg/l then the NO_2 form would become a "must monitor" priority for health reasons.	8
Nitrogen, total	Provides little practical information.	8
Phosphorus, dissolved ortho	Total phosphorus considered best measure of potential phosphorus available for biological utilization.	8
Sediment minerology	May provide sediment source data.	8
Silver, total	Total form never measured, dissolved values very low (maximum 3 μg/l).	8
Strontium, dissolved	Strontium levels high in Belle Fourche River (maximum 6,700 μg/l) but has little biological effect.	8
Tin, dissolved	Very low levels (maximum 30 μg/l), few adverse effects.	8
Titanium, dissolved	Reported values low (maximum 25 μg/l).	8
Vanadium, dissolved	Reported values very low (maximum 40 μg/l).	8
Zinc, total	Values low to moderate (maximum 1,900 μg/l).	8
Zirconium, dissolved	Reported values very low (maximum 7 μg/l).	8

†Parameters are (except for sediment minerology) determined in water samples only.
††For full explanation of category codes, see Section 10.

research projects are not considered in this report. These concerns are important and should not be neglected, but they require considerations that are beyond the scope of this report.

The reasons for monitoring each parameter listed on Tables 40-42 are categorized by the following classification scheme:

Priority I - Must Monitor Parameters

1. Parameters essential for the interpretation of water quality data. This consideration includes parameters such as temperature, pH, and flow, which are necessary to determine loadings, chemical equilibria, biological response, or other factors affecting other parameters.

2. Parameters presently commonly exceeding existing water quality criteria. Consideration is of EPA water quality criteria for beneficial water uses (see codes presented earlier). In cases where EPA criteria have not yet been defined, criteria recommended by the National Academy of Sciences (1973) are used.

3. Parameters expected to increase to levels exceeding water quality criteria unless extreme care is taken. This category includes organic chemical compounds that are expected to be present in future discharges from energy developments and that could reach lethal, mutagenic, or carcinogenic levels unless extreme care is taken. The beneficial use symbols for water quality criteria expected to be exceeded are used here.

4. Parameters that are useful "trace" or "indicator" parameters. These include parameters that, although not causing substantial impact to the aquatic environment themselves, are used to define pollution sources, estimate other parameters of concern, or provide general data on the overall quality of the water. An example would be conductivity, which provides an estimate of TDS levels.

5. Parameters expected to be altered by energy development activities so as to present a threat to a rare or endangered species. These include parameters that do not normally affect aquatic life at encountered levels but that as a result of unique circumstances, may affect a threatened or endangered species. In the Little Missouri and Belle Fourche River Basins, this category situation is not presently known to exist.

Priority II - Major Interest Parameters

6. Potential pollutants of concern. This category includes parameters whose reported levels in the Little Missouri and Belle Fourche River Basins are presently within acceptable limits for beneficial water uses but whose ambient levels could be altered by planned regional developments to levels that impair those uses. This differs from category 3 in that, while category 3 parameters are expected to

produce problems (either environmental or abatement/disposal), category 6 are those which might be a problem only if unrestricted development were permitted.

7. Marginal "trace" or "indictor" parameters. These are parameters that may be used to provide general data on overall quality of the water, to locate pollutant source areas, or to estimate other parameters. Such parameters are not presently routinely monitored, or they provide little advantage over other measurements being made.

Priority III - Minor Interest Parameters

8. Parameters that are present at very low levels and are unlikely to be significantly changed by planned regional development, that are fairly easily monitored but have little effect on beneficial water uses at encountered levels, or that provide little useful data for monitoring energy or other development. Many of these parameters are currently being monitored on a regular basis in the Little Missouri-Belle Fourche River study area; however, for purposes of monitoring energy impact development, these parameters are not necessary.

Priorities are arranged alphabetically within Tables 40-42. The order of their appearance is not intended to suggest a ranking of relative importance.

Although frequency of measurement is not addressed by the priority listings, whenever possible at least monthly collection is recommended for most water quality parameters. Standard analytical techniques should be utilized, and the data should be processed and entered into data bases as soon as possible after collection. It should be stressed that changing conditions within the study area may cause some changes in the priority listings, especially addition of currently unmonitored compounds for which little data are available.

Analysis of bottom sediment samples on an annual or semiannual basis should be performed. Total organic carbon, BOD, grain size, and elemental data should be determined. Sediments from Keyhole Reservoir should also be sampled and analyzed on a regular basis. Because extensive organic extractions and analyses from sediment samples are expensive, it is not recommended that analysis for specific toxic organic compounds be performed on a routine basis. These analyses should be performed as special studies rather than on a routine monitoring basis at the present time. Bottom sediment parameters of interest are included on Table 40. Priority ranking of parameters for sediment samples followed the same considerations used in establishing priorities for the water column.

BIOLOGICAL PARAMETERS

The collection of biological data in the Little Missouri and Belle Fourche River Basins would be an effective complementary tool for assessing the impact of energy or irrigation development. Biological investigations are of special significance in water quality monitoring programs because they offer a means of identifying areas affected by pollution and assessing the degree of stress from relatively small changes in physical-chemical parameters. Aquatic organisms act as natural monitors of water quality because the composition and structure of plant and animal communities are the result of the biological, chemical, and physical interactions within the system. When only periodic physical-chemical data are collected, an episodic event such as a flash flood or spill may go undetected. The biota affected by an occasional event may require weeks or months to recover. In addition, many biological forms, which accumulate various chemicals preferentially, serve as both integrative and concentration mechanisms that may permit detection of pollutants not detected in the water itself. Finally, because biota are affected by all materials and conditions present in the system, they could be the first indication of a major hazard posed by some unsuspected, unmonitored compound.

Biological monitoring should be initiated in a regular fashion within the Little Missouri and Belle Fourche River systems. It should not be viewed as an alternative to other monitoring but as a complementary tool for improving the efficacy of monitoring programs. A comprehensive biological monitoring program is recommended to gather baseline data and to permit the eventual refinement of techniques. Such a monitoring effort should be designed to obtain standardized, reproducible data that may be compared from station to station across time. Sampling methods and sites will obviously differ for the different biological communities and parameters. However, for a given community and parameter, sites that have similar characteristics should be selected and the same sampling device and technique should be used for collection efforts. Replicate samples should be routinely collected and analyzed separately for quality assurance purposes. Of primary interest in biological monitoring is the assessment of changes in community structure over time and space; for such comparisons a minimum of a single year of baseline data is necessary and the accumulation of several year's data is generally required to demonstrate natural temporal variations in the communities in the basins.

Taxonomic groups considered appropriate for biological monitoring in the Little Missouri and Belle Fourche River Basins are discussed below.

Macroinvertebrates

These larger forms are relatively easy to collect, quantify, and identify to a meaningful taxonomic level. Being relatively stationary they are unable to escape oncoming waste materials, and their life cycles are sufficiently long to prevent an apparent recovery to periodic relief from pollution. Seasonal sampling (based on stream temperature and flows) should be conducted, although annual or semiannual records could be beneficial if taken during comparable seasons. Care must be taken to allow sufficient time between sampling of identical areas to permit disturbed populations to reestablish themselves (e.g., six weeks). Exploratory macroinvertebrate sampling in lakes should be conducted to determine if sufficient macrobenthos exist to make monitoring them worthwhile.

Periphyton

The periphyton, like the macrobenthos, are unable to escape pollution events. Widespread, rapid growing, and easy to sample, they are the primary producers in flowing systems and provide basic data on the overall quality of streams and lakes.

Fish

Fish represent the top of the aquatic food chains and respond to the cumulative effects of stresses on lower forms as well as to direct stresses. In addition, they represent an element of intense public concern. Unlike the macroinvertebrate and periphyton communities, fish have considerable mobility and may be able to escape localized pollution events. Fish are readily sampled, and identification is not difficult in most cases.

Phytoplankton

Present in nearly all natural waters, phytoplankton are easily sampled and can provide basic data on productivity, water quality, potential or occurring problems, etc. Phytoplankton sampling is recommended in lakes and ponds but is not recommended for stream monitoring in these basins.

Zooplankton

Zooplankton include organisms that graze upon phytoplankton and in turn provide a major food supply for higher forms. The zooplankton can be responsible for unusually low phytoplankton levels as a result of their grazing activities. These forms may provide basic information on environmental regimes and, because of their relatively short life spans and fecundity, may be the first indication of subacute pollution hazards. Zooplankton sampling is also recommended primarily for lakes and ponds in the study basins.

Microorganisms

Coliform bacteria are generally considered to be indicative of fecal contamination and are one of the most frequently applied indicators of water quality. Criteria exist for bathing and shellfish harvesting waters (U.S. Environmental Protection Agency 1976b). Other microbiological forms may be useful in the study basins, but these have not been identified and are not discussed.

An annotated list of parameters (Tables 43-44) is recommended for monitoring the impact of energy resource development in the Little Missouri and Belle Fourche River Basins. The Priority I category includes those parameters that generally demonstrate an observable response to the type of stress conditions anticipated as a result of increased energy development activities, and for which effective monitoring techniques have been developed. It is recommended that Priority I parameters be incorporated into any water quality monitoring program developed in the basin for energy impact assessment. The Priority II parameters are those that may be of value to the

TABLE 43. PRIORITY I BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

TABLE 43. PRIORITY I BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Macroinvertebrates	Counts and identification	Total number/taxa/unit sampling area or unit effort	Provides data on species present, community composition, etc., that may be related to water quality or other environmental considerations
	Biomass	Weight/unit sampling area or unit effort	Provides data on standing crop
Periphyton	Biomass	Weight/unit substrate	Provides data on standing crop
	Growth rate	Weight/unit substrate time	Provides data on productivity
	Identification and estimation of relative abundances*	Taxa present	Indicative of community composition that may be related to water quality rate of recovery from a biological catastrophe, etc.

*Gross estimates of the quantity or percent of each taxon should be made rather than specific count data/unit area.

(Continued)

TABLE 43. (Continued)

Taxonomic Group	Parameter	Expressed As	Reason for Sampling
Fish	Identification and enumeration	Species present** (includes measurement of size, weight, and sex determination)	Provides data on water quality, environmental conditions, and possibly on water uses. Different species respond to different stresses.
	Toxic substances in tissue	Weight substance/unit tissue weight (by species)	Indication of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water, may pose a health hazard in itself.
Zooplankton	Identification and count	Species present	Provides basic data on environmental conditions.
		Total unit volume or biomass Number/species/unit volume	Provides data upon community composition, environmental conditions, and available food size ranges.

*Count data should be provided for each species.

(Continued)

TABLE 43. (Continued)

Taxonomic Group	Parameters	Expressed As	Reason for Sampling
Macrophytes	Species identification and community association	Areal coverage and community	Indication of stream stability, sedimentation, and other factors. Spread of phreatophytes could be a problem in the basin because of their effect on water quality. Initial survey and thereafter occasional examination of aquatic and stream (lake) side plants is recommended.
Phytoplankton	Chlorophyll a	µg/liter	Indication of overall lake productivity-excessive levels often indicate enrichment problems.
	Identification and enumeration	Number/taxa/unit volume Total number/sample (unit volume) or biomass	The presence of specific taxa in abundance is often indicative of water quality, and the taxa may in themselves pose biological problems.
Microorganisms	Total fecal coliform	Number/unit volume	Indicative of fecal contamination of water supplies and probable presence of other pathogenic organisms.

TABLE 44. PRIORITY II BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE LITTLE MISSOURI AND BELLE FOURCHE RIVER BASINS

Taxonomic Group	Parameter	Expressed As	Reason for Sampling
Macroinvertebrates	Toxic substances in tissue	Weight substance/unit tissue weight	Indicative of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water itself.
Periphyton	Chlorophyll a	Unit substrate area	Indicative of productivity of area and general health of the periphyton community.
	Taxonomic counts	Number/taxa/unit substrate area	Provides additional data on periphyton community composition.
Fish	Biomass	Total weight/sampling effort or unit volume	Indicative of secondary productivity of the water body.
	Flesh tainting	Rating scale (by species)	Indicative of high levels of organic compounds Likely to be noticed by public. Could indicate pollution from several sources to be the result of other causes.

(Continued)

TABLE 44. (Continued)

Taxonomic Group	Parameter	Expressed As	Reason for Sampling
Fish	Size	Length, weight/individual, or range and average size/species	Provides an indication of the age of the community, breeding potential, and secondary productivity rates.
	Condition factor	Weight/length (by species)	Indicative of general health of fish community and availability of food.
	Growth rate	Age/length (by species)	Provides data on overall health of the fish community and environmental conditions. Could indicate the presence of subacute pollutants.
Zooplankton	Biomass	Weight/unit volume	Basic data on abundance and overall standing crop.
	Eggs, Instars, etc.	Species present	Provides basic data on age distributions, presence of seasonal forms, or the existence of cyclic pollution events.
	Toxic substance in tissue	Weight/unit tissue (by species)	May serve as bioconcentrator for specific compounds.

basins but that are not generally considered to be as likely to provide useful data as those in the Priority I category; these parameters should only be collected in addition to Priority I parameters if time and money are available.

It should be noted that the count and biomass determinations in Tables 43 and 44 are not productivity measurements. Rather they are expressions of standing crops, and although indicative of general productivity, the measurements are really quite different. Productivity data are expressed in units of mass/volume (or area)/unit time.

11. ASSESSMENT OF EXISTING MONITORING NETWORK

Estimations can be made regarding the possible impact of proposed developments on water quality, but only after operation can the actual impact be assessed. A well-developed sampling network for the monitoring of environmental parameters is helpful, not only in controlling and assessing pollution from existing projects, but also in providing valuable information for evaluating future projects.

Twenty-two U.S. Geological Survey sampling stations in the Little Missouri and Belle Fourche River Basins were analyzed to evaluate trends in surface water quality (Table 26). There are a number of additional stations throughout the basins that are maintained by miscellaneous sources, but it is felt that the USGS stations examined in this report are in themselves well situated for future investigation of surface waters impacted by energy development. However, many of the stations in the basin are not regularly monitored. The uppermost Little Missouri River station near Alzada, Montana, has not been sampled since 1970, and, in total, data for only one year were collected there. The Box Elder Creek and Little Missouri River at Camp Crook stations were sampled only between 1972 and 1973. The Medora station for the Little Missouri River and the Indian Creek station in the Belle Fourche Basin have not been monitored since 1976. At the station on Raven Creek in the Belle Fourche Basin, data on trace elements in bottom sediments were collected during 1978, but no data were gathered on the water column except temperature and flow. Most of the information available from the Redwater Creek station, except for sediment particle size, dates back to 1970. It is apparent, then, that although the USGS network is well laid out for monitoring energy impact on the study area, it is presently not being adequately maintained for this purpose.

It should be noted that there is no known regional ground-water monitoring network in the study basins. The USGS has for the past several years been conducting periodic sampling of several hundred wells in the region for areal appraisals of the ground-water aquifers but is not monitoring for trends or energy-related changes in the ground-water system (J. Moreland, USGS, Helena, Montana, Personal communication, 1978). It is felt that the establishment of a regular ground-water monitoring network, especially one that could measure for potential trace element and organic contamination related to mining activities, would be of great value. Such a program is most needed around underground mine and in situ project sites.

Fairly good baseline data are available from the USGS stations at Elm Springs in the Belle Fourche River Basin and at Watford City in the Little Missouri Basin, and these locations should be considered for weekly sampling of top-priority parameters. More intensive sampling of the stations in the

Belle Fourche River above Keyhole Reservoir should be attempted since these locations are well situated for observation of water quality degradation as the result of mining and coal conversion facilities. If funding permits, weekly sampling in the Belle Fourche River near Moorcroft would also be desirable. In general, data for the Belle Fourche Basin are much more complete than those for the Little Missouri Basin, presumably because of the highly variable flow in the latter river. For this reason, future energy development in the Little Missouri Basin would require greater modificiation of the sampling network than would be required in the Belle Fourche Basin.

Physical and chemical parameters monitored by the sampling network in the Little Missouri and Belle Fourche River Basins, and their average annual frequency of measurement are shown in Table 45. This table was constructed from data inventories present in STORET. The average number of times a parameter was sampled each year over the period of record is indicated for each station. Although the completed sampling network in the basins should be adequately located for monitoring the impact of energy development activities in the basins, there are some data collection problems within the sampling net that reduce the interpretive utility of the accumulated data. A good number of the parameters considered to have highest selection priority (Table 40) for monitoring of energy development impact, particularly the trace elements and nutrients, are sampled only intermittently or infrequently. At many of the stations in the study area, trace element data are not gathered at all; where they are collected, generally only the dissolved form is available for analysis. Valuable information on sediment particle size distributions was gathered in the 1950's at many of the basin stations, but sampling for these parameters has since been discontinued. Even when data on major parameters such as the salts are regularly gathered, the data are rarely collected on similar dates across the stations, making spatial or temporal comparisons difficult. A few other priority I parameters, such as phenols, oils, and greases, are completely lacking from the existing network or are sampled only rarely; most of the pesticide data date back to the early 1970's and are not available for more recent years. Very little biological data have been gathered by the existing monitoring network in the basins. These problems are aggravated by the unavoidable periodic nature of many of the tributaries flowing through the study area.

If program restrictions on funding or personnel necessitate, the number of stations regularly sampled in the basins for purposes of monitoring the impact of energy resource development could be substantially reduced. Those USGS stations indicated on Table 46 are recommended as having the highest sampling priority in the Belle Fourche and Little Missouri River Basins for monitoring energy development activities there. The addition of stations on Whitewood Creek and on the Belle Fourche River immediately upstream from Whitewood Creek is recommended, as are the additions of a station in the Little Missouri Basin in its Wyoming headwaters and a station in Donkey Creek above Gillette. Of the 12 priority stations recognized in the study area, sites in the Belle Fourche River below Moorcroft and at Elm Springs are the best located for the maintenance of any continuous monitoring activities.

TABLE 45. SELECTED PARAMETERS MONITORED BY THE U.S. GEOLOGICAL SURVEY IN THE BELLE FOURCHE AND LITTLE MISSOURI RIVER BASINS AND THEIR AVERAGE ANNUAL FREQUENCY OF MEASUREMENT

Parameter†				USGS STATION NUMBERS																					
				06334000	06334500	06334630	06335000	06335500	06336000	06337000	06425720	06425780	06425950	06426400	06426500	06427850	06428500	06429500	06429900	06430500	06434500	06436700	06436800	06437000	06438000
00010	WATER	TEMP	CENT	7*	6	6	12	11	10	11	5	7	1*	5	10	11	16	6	5	13	8	2	7	10	11
00061	STREAM	INST. FLOW	CFS	7*	13	19	11	12	5	9	10	10	1*	5	10	10	13	6	5	15	8	2	7	9	11
00095	CNDUCTVY	AT 25 C	MICROMHO	7*	12	15	12	12	10	10	3	5	--	5	8	8	9	1*	--	6*	12	1	13	15	12
00300	D.O.		MG/L	--	--	--	--	--	--	8	3	5	--	5	8	10	3	--	--	--	--	--	--	--	10
00400	PH		SU	7*	12	15	3	4	1	10	3	5	--	5	8	11	8	--	--	6*	11	--	13	14	13
00410	T ALK	CACO3	MG/L	7*	12	15	3	4	1	10	3	5	--	5	8	12	11	1*	1*	6*	12	1	13	14	8
00440	HCO3 ION	HCO3	MG/L	7*	12	15	3	4	1	10	3	5	--	5	8	12	11	1*	1*	6*	12	1	13	14	8
00445	CO3 ION	CO3	MG/L	7*	12	15	3	4	1	10	3	5	--	4	8	12	11	--	--	6*	11	--	12	13	7
00625	TOT KJEL	N	MG/L	--	--	--	--	--	--	7	3	5	--	4	8	10	3	--	--	--	--	--	--	--	7
00630	NO2 & NO3	N-TOTAL	MG/L	--	--	--	--	--	--	8	3	4	--	4	8	10	3	--	--	--	--	--	--	--	6
00665	PHOS-TOT	P	MG/L	--	12	--	--	--	--	8	3	5	--	4	8	9	7	1*	1*	--	10	1	11	12	10
00666	PHOS-DISS	P	MG/L	--	12	5	4	4	1	5	--	--	--	--	--	--	--	1*	1*	--	9	1	10	11	7
00900	TOT HARD	CACO3	MG/L	7*	12	15	3	4	1	7	3	5	--	4	8	11	11	1*	1*	6*	10	1	13	15	9
00915	CALCIUM	DISS	MG/L	7*	12	15	3	4	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	9
00925	MGNSIUM	DISS	MG/L	7*	12	15	3	4	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	9
00930	SODIUM	DISS	MG/L	7*	12	15	3	4	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	7
00935	PTSSIUM	K, DISS	MG/L	7*	12	15	3	4	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	7
00940	CHLORIDE	CL	MG/L	7*	12	15	3	6	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	9
00945	SULFATE	SO4-TOT	MG/L	7*	12	15	3	6	1	7	3	5	--	4	8	11	11	1*	1*	6*	12	1	13	15	10
00950	FLORIDE	F, DISS	MG/L	7*	12	15	--	--	--	3	--	--	--	--	--	--	--	1*	1*	--	--	--	--	--	--
00955	SILICA	DISS	MG/L	7*	12	15	3	6	1	7	3	5	--	4	8	15	11	1*	1*	6*	10	1	12	13	7
01002	ARSENIC	AS, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	--	2
01007	BARIUM	BA, TOT	UG/L	--	--	--	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
01012	BERYLIUM	BE, TOT	UG/L	--	--	--	--	--	--	3	2	3	--	--	3	3	1	--	--	--	--	--	--	--	--
01022	BORON	B, TOT	UG/L	--	--	--	--	--	--	3	--	--	--	--	--	5	3	--	--	--	--	--	--	--	--

†Parameters are listed by STORET code, name, form, and unit.
*Indicates parameter occurring only 1 year.
--Parameter not sampled.

(Continued)

TABLE 45. (Continued)

				USGS STATION NUMBERS																					
Parameter†				06334000	06334500	06334630	06335000	06335500	06336000	06337000	06425720	06425780	06425950	06426400	06426500	06427850	06428500	06429500	06429900	06430500	06434500	06436700	06436800	06437000	06438000
01027	CADMIUM	CD, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	--	2
01034	CHROMIUM	CR, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	2*	4
01035	COBALT	CO, TOT	UG/L	--	--	--	--	--	--	4	--	--	--	--	--	--	1	--	--	--	--	--	--	--	3
01042	COPPER	CU, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	--	3
01045	IRON	FE, TOT	UG/L	3*	--	--	--	--	--	4	2	3	--	--	3	5	3	--	--	6*	--	--	--	--	3
01051	LEAD	PB, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	2	1	--	--	--	--	--	--	--	3
01055	MANGANESE	MN	UG/L	--	--	--	1	--	--	4	2	3	--	1*	3	3	1	--	--	--	1	--	1	--	3
01062	MOLY	TOTAL	UG/L	--	--	--	--	--	--	3	2	3	--	--	3	3	1	--	--	--	--	--	--	--	--
01067	NICKEL	NI-TOT	UG/L	--	--	--	--	--	--	3	2	3	--	--	3	3	1	--	--	--	--	--	--	--	--
01075	SILVER	AG, DISS	UG/L	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
01077	SILVER	AG, TOT	UG/L	--	--	--	--	--	--	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1
01092	ZINC	ZN, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	--	3
01105	ALUMINUIM	AL, TOT	UG/L	--	--	--	--	--	--	3	2	3	--	--	3	3	1	--	--	--	--	--	--	--	1
01132	LITHIUM	LI, TOT	UG/L	--	--	--	--	--	--	3	2	3	--	--	3	3	1	--	--	--	--	--	--	--	--
01147	SELENIUM	SE, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	1	--	--	--	--	--	--	--	3
70301	DISS SOL	SUM	MG/L	7*	12	15	3	6	1	7	3	5	--	4	8	13	11	1*	1*	6*	10	1	12	13	6
71900	MERCURY	HG, TOT	UG/L	--	--	--	--	--	--	4	2	3	--	--	3	3	2	--	--	--	--	--	--	1	2

†Parameters are listed by STORET code, name, form, and unit.
*Indicates parameter occurring only 1 year.
--Parameter not sampled.

TABLE 46. U.S. GEOLOGICAL SURVEY STATIONS RECOMMENDED TO HAVE THE HIGHEST SAMPLING PRIORITY IN THE LITTLE MISSOURI-BELLE FOURCHE STUDY AREA FOR MONITORING ENERGY DEVELOPMENT

Station STORET Number	Station Name
06425720	Belle Fourche River below Rattlesnake Creek, WY
06426400	Donkey Creek near Moorcroft, WY
06426500	Belle Fourche River below Moorcroft, WY
06428500	Belle Fourche River at WY-SD State line
not established	Belle Fourche River above Whitewood Creek, SD
not established	Whitewood Creek at mouth, SD
06437000	Belle Fourche River near Sturgis, SD
06438000	Belle Fourche River near Elm Springs, SD
06334000	Little Missouri River near Alzada, MT
06335500	Little Missouri River at Marmarth, ND
06336000	Little Missouri River at Medora, ND
06337000	Little Missouri River near Watford City, ND

REFERENCES

Adams, W. 1975. Western Environmental Monitoring Accomplishment Plan. Draft report, U.S. Environmental Protection Agency, EMSL-Las Vegas, NV. 48 pp.

Atwood, G. 1975. The Strip-Mining of Western Coal. Scientific American 223(6): 23-29.

Bailey, R. M., J. E. Fitch, E. S. Herald, E. A. Lachner, C. C. Lindsey, C. R. Robins, and W. B. Scott. 1970. A List of Common and Scientific Names of Fishes from the United States and Canada. Third Edition, American Fisheries Society Special Publication #6. 150 pp.

Baria, D. N. 1975a. Evaluation of Gasification and Liquefaction Processes Using North Dakota Lignite. University of North Dakota Engineering Experiment Station, Grand Forks, ND. 130 pp.

Baria, D. N. 1975b. A Survey of Trace Elements in North Dakota Lignite and Effluent Streams from Combustion and Gasification Facilities. University of North Dakota Engineering Experiment Station, Grand Forks, ND. 64 pp.

Briggs, J. C., and J. F. Ficke. 1977. Quality of Rivers in the United States, 1975 Water Year -- Based on the National Stream Quality Accounting Network (NASQAN). USGS Open-File Report #78-200. U.S. Geological Survey, Reston, VA. 436 pp.

Brown, D. M. 1952. Lignite Resources of South Dakota. USGS Information Circular #159, U.S. Geological Survey, Washington, D. C. 18 pp.

Campbell, T. C., and S. Katell. 1975. Long Distance Coal Transport: Unit Trains or Slurry Pipelines. U.S. Bureau of Mines Information Circular #8690. Process Evaluation Group, Morgantown, WV. 31 pp.

Carlson, C. G., and S. B. Anderson. 1965. Sedimentary and Tectonic History of North Dakota Part of Williston Basin. In: Bulletin of the American Association of Petroleum Geologists 49(11): 1893-1907.

Corsentino, J. S. 1976. Projects to Expand Fuel Sources in the United States: Survey of Planned or Proposed Coal, Oil Shale, Tar Sand, Uranium, and Geothermal Supply Expansion Projects and Related Infrastructure in States West of the Mississippi River. U.S. Bureau of Mines Information Circular #8719. U.S. Government Printing Office, Washington, D. C. 208 pp.

Darton, N. H. 1909. Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming. USGS Professional Paper #65. U.S. Geological Survey, Washington, D. C. 105 pp.

Federal Energy Administration. 1974. Project Independence Blueprint Final Task Report. Coal. 175 pp.

Glass, G. B. 1976. Wyoming Coal Directory. Wyoming Geological Survey. 21 pp.

Gries, J. P. 1974. Mineral Resources of the Black Hills Area, South Dakota and Wyoming. U.S. Bureau of Mines Information Circular #8660. U.S. Department of Interior, Washington, D. C. 61 pp.

Harza Engineering Company. 1976. Analyses of Energy Projections and Implications for Resource Requirements. Chicago, IL. 130 pp.

Haun, J. D., and H. C. Kent. 1965. Geologic History of the Rocky Mountain Region. In: Bulletin of the American Association of Petroleum Geologists 49(11): 1781-1800.

Hughes, E. E., E. M. Dickson, and R. A. Schmidt. 1974. Control of Environmental Impacts from Advanced Energy Sources. #EPA-600/2-74-002. Stanford Research Institute. U.S. Environmental Protection Agency, Washington, D. C. 326 pp.

Lord, W. B., S. K. Tubbesing, and C. Althen. 1975. Fish and Wildlife Implications of Upper Missouri Basin Water Allocation. Program on Technology, Environment and Man Monograph #22. University of Colorado, Boulder, CO. 114 pp.

McGuinness, C. L. 1963. The Role of Ground Water in the National Water Situation. U.S. Geological Survey Water-Supply Paper #1800. U.S. Government Printing Office, Washington, D. C. 1121 pp.

McKee, J. E., and H. W. Wolf. 1963. Water Quality Criteria. Resources Agency of California State Water Quality Control Board, Publication #3-A, Second Edition. Sacramento, CA. 548 pp.

McMillion, L. G. 1978. Ground-Water Quality Monitoring of Western Coal Strip Mining: Identification and Prioritization of Potential Pollution Sources (draft). U.S. Environmental Protection Agency, EMSL-Las Vegas, NV. 227 pp.

Missouri Basin Inter-Agency Committee. 1969a. Comprehensive Framework Study-Missouri River Basin. Volume 2: Historical Perspective of the Mississippi River. Basin History of the Framework Study, Existing Water and Land Resources Development. U.S. Government Printing Office, Washington, D. C. 75 pp.

Missouri Basin Inter-Agency Committee. 1969b. Comprehensive Framework Study-Missouri River Basin. Volume 6: Appendices - Land Resources Availability, Hydrologic Analyses, and Projections. U.S. Government Printing Office. Washington, D. C. 317 pp.

Missouri Basin Inter-Agency Committee. 1971a. The Missouri River Basin Comprehensive Framework Study. #5233-0007. Volume 1. U.S. Government Printing Office, Washington, D. C. 273 pp.

Missouri Basin Inter-Agency Committee. 1971b. The Missouri River Basin Comprehensive Framework Study: Fish and Wildlife Tentative Needs and Problems, Western Dakota Tributaries Subbasin. Task Force on Fish and Wildlife, Work Group on Needs and Problems. 104 pp.

Missouri River Basin Commission. 1978a. Report on Yellowstone Basin and Adjacent Coal Area Level B Study. Volume 6: North Dakota Tributaries. North Dakota Study Team. Omaha, NE. 352 pp.

Missouri River Basin Commission. 1978b. Report on the Yellowstone Basin and Adjacent Coal Area. Volume 8: Northeast Wyoming. Northeast Wyoming Study Team. Omaha, NE. 369 pp.

National Academy of Sciences. 1973. Water Quality Criteria, 1972. #EPA-R3-73-033. U.S. Environmental Protection Agency, Washington, D. C. 594 pp.

North Central Power Study Coordinating Committee. 1971. Report of Phase 1, Volume 2: Study of Mine-Mouth Thermal Power Plants With Extra High Voltage Transmission for Delivery of Power to Load Centers. U.S. Bureau of Reclamation. Billings, MT. 456 pp.

North Dakota State Water Commission. 1975a. The West River Study. Volume 1: Main Report. Information Series #30. SWC Project #1543. Bismark, ND. 274 pp.

North Dakota State Water Commission. 1975b. The West River Study. Volume 2: Appendices A-C, Basic Data, Hydrology, Soils. Information Series #30. SWC Project #1543. Bismark, ND. 294 pp.

North Dakota State Water Commission. 1975c. The West River Study. Volume 3: Appendices D-G, Mineral Resources, Potential Projects, Economic Value of Water, Environmental Assessment. Information Series #30, SWC Project #1543. Bismark, ND. 279 pp.

Northern Great Plains Resource Program. 1974. Water Quality Subgroup Report (Draft). 530 pp.

Powder River Areawide Planning Organization. 1977. Water Quality Management Plan, Campbell County, Johnson County, Sheridan County, State of Wyoming. #EPA-908/3-77-003. U.S. Environmental Protection Agency. Sheridan, WY. 295 pp.

Riis, M. 1977. Resource Inventory of the Belle Fourche River Basin. South Dakota Water Plan Volume 11-B, Section 9. Division of Resources Management. South Dakota Department of Natural Resources Development. 186 pp.

Seager, O. A., D. L. Blackstone, Jr., G. R. Downs, W. M. Laird, and L. L. Sloss. 1942. Stratigraphy of North Dakota. In: Bulletin of the American Association of Petroleum Geologists 26(8): 1414-1423.

Smith, J. B. 1972. Strippable Coal Reserves of Wyoming: Location, Storage, and Characteristics of Coal and Overburden. U.S. Bureau of Mines Information Circular #8538. U.S. Department of Interior, Washington, D. C. 51 pp.

South Dakota Department of Natural Resources Development. 1972. Resource Inventory of the Little Missouri River Basin. South Dakota Water Plan Volume II-B, Section 1. Division of Resources Management. 92 pp.

U.S. Bureau of Indian Affairs. 1974. Crow-Ceded Area Coal Lease - Westmoreland Resources Mining Proposal, Final Environmental Statement #EIS-MS-74-0178-F. Billings, MT. 353 pp.

U.S. Bureau of Reclamation. 1972. Appraisal Report on Montana-Wyoming Aqueducts. Pick-Sloan Missouri Basin Program. 47 pp.

U.S. Department of Interior. 1974. Proposed Development of Coal Resources in the Eastern Powder River Basin Final Environmental Impact Statement. Volume IV. U.S. Bureau of Land Management. #FES 74-55. U.S. Government Printing Office, Washington, D. C. 479 pp.

U.S. Environmental Protection Agency. 1971a. Report on Pollution Affecting Water Quality of the Cheyenne River System, Western South Dakota. Office of Enforcement, Division of Field Investigations, Denver, CO. 89 pp.

U.S. Environmental Protection Agency. 1971b. The 1968 Inventory of Municipal Waste Facilities. EPA Publication #OWP-1, Volume 9. U.S. Government Printing Office, Washington, D. C. 93 pp.

U.S. Environmental Protection Agency. 1975a. Evaluation of Proposed NPDES Permit Limitations for Homestake Mining Company. #EPA-330/2-75-006. Office of Enforcement, Denver, CO. 26 pp.

U.S. Environmental Protection Agency. 1975b. Water Programs: National Interim Primary Drinking Water Regulations. Federal Register 40(248): 59566-59574.

U.S. Environmental Protection Agency. 1976a. National Interim Primary Drinking Water Regulations. #EPA-570/9-76-003. Office of Water Supply, Washington, D. C. 159 pp.

U.S. Environmental Protection Agency. 1976b. Quality Criteria for Water. #EPA-440/9-76-023. Washington, D. C. 501 pp.

U.S. Environmental Protection Agency. 1976c. Report on Lake Sakakawea, Dunn, McKenzie, McLean, Mercer, Mountrail, and Williams Counties, North Dakota. Working Paper #575. CERL-Corvallis, OR, and EMSL-Las Vegas, NV. 64 pp.

U.S. Environmental Protection Agency. 1977a. Advanced Fossil Fuels and the Environment. #EPA-600/9-77-013. U.S. EPA Decision Series. Research and Development Technical Information Staff, Cincinnati, OH. 23 pp.

U.S. Environmental Protection Agency. 1977b. Report on Keyhole Reservoir, Crook County, Wyoming. Working Paper #888. CERL-Corvallis, OR, and EMSL-Las Vegas, NV. 40 pp.

U.S. Geological Survey. 1975a. Proposed Plan of Mining and Reclamation, Belle Ayr South Mine, Amax Coal Company, Coal Lease W-0317682, Campbell County, Wyoming. Final Environmental Statement #FES75-86, Volume I. U.S. Department of Interior. 193 pp.

U.S. Geological Survey. 1975b. Proposed Plan of Mining and Reclamation Cordero Mine, Sun Oil Company, Coal Lease W-8385, Campbell County, Wyoming. Final Environmental Statement #DES 75-65. U.S. Department of Interior. 331 pp.

U.S. Geological Survey. 1977a. Proposed Mining and Reclamation Plan, East Gillette Mine, Kerr-McGee Corporation, Coal Leases W-311810, W-312311, and W-313668, Campbell County, Wyoming. Draft Environmental Statement. U.S. Department of Interior, Washington, D. C. 390 pp.

U.S. Geological Survey. 1977b. Proposed Mining and Reclamation Plan, Pronghorn Mine, Campbell County, Wyoming. Draft Environmental Statement. U.S. Department of Interior, Washington, D. C. 87 pp.

University of Oklahoma and Radian Corporation. 1977a. Energy from the West: A Progress Report of a Technology Assessment of Western Energy Resource Development. Volume II: Detailed Analyses and Supporting Materials. #EPA-600/7-77-072b. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D. C. 805 pp.

University of Oklahoma and Radian Corporation. 1977b. Energy from the West: A Progress Report of a Technology Assessment of Western Energy Resource Development. Volume III: Preliminary Policy Analysis. #EPA-600/7-77-072c. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D. C. 176 pp.

Utah State University. 1975. Colorado Regional Assessment Study. Part II: Detailed Analysis: Narrative Description Data, Methodology and Documentation. Contract #WQ5AC054. Logan, UT. 479 pp.

Warner, D. L. 1974. Rationale and Methodology for Monitoring Ground Water Polluted by Mining Activities. #EPA-680/4-74-003. U.S. Environmental Protection Agency, Las Vegas, NV. 76 pp.

Water Resources Council. 1968. The Nations Water Resources. U.S. Government Printing Office, Washington, D. C. 388 pp.

Wewerka, E. M., J. M. Williams, P. L. Wanek, and J. D. Olsen. 1976. Environmental Contamination from Trace Elements in Coal Preparation Wastes: A Literature Review and Assessment. #EPA-600/7-76-007. U.S. Environmental Protection Agency. Research Triangle Park, NC. 69 pp.

Wyoming Geological Association Technical Studies Committee. 1965. Geologic History of Powder River Basin. In: Bulletin of the American Association of Petroleum Geologists 49(11): 1893-1907.

Wyoming State Engineers Office. 1972. Water and Related Land Resources of Northeastern Wyoming. Wyoming Water Planning Program Report #10. Cheyenne, WY. 243 pp.

Wyoming State Engineers Office. 1973. The Wyoming Framework Water Plan. Wyoming Water Planning Program. Cheyenne, WY. 243 pp.

APPENDIX A

CONVERSION FACTORS

In this report, metric units are frequently abbreviated using the notations shown below. The metric units can be converted to English units by multiplying the factors given in the following list:

Metric unit to convert	Multiply by	English unit to obtain
Centimeters (cm)	0.3937	Inches
Cubic meters (m^3)	8.107×10^{-4}	Acre-feet
Cubic meters/sec (m^3/sec)	35.315	Cubic feet/sec
Hectares (ha)	2.471	Acres
Liters/kilogram/(1 kg)	239.64	Gallons/ton
Kilograms (kg)	2.205	Pounds
Kilograms (kg)	1.102×10^{-3}	Tons (short)
Kilometers (km)	0.6214	Miles
Liters (1)	6.294×10^{-3}	Barrels (crude oil)
Liters	0.2642	Gallons
Meters (m)	3.281	Feet
Square kilometers (km^2)	247.1	Acres
Square Kilometers	0.3861	Square miles

APPENDIX B

CHEMICAL AND PHYSICAL DATA

TABLE B-1. DISSOLVED SOLIDS, SUM OF CONSTITUENTS (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	1387(1060-1860)9	1133(683-1700)16	--	--	--	--	--
3346	--	1098(576-1580)11	962(389-1760)20	--	--	--	--	--
3350	--	1830(-)1	1057(974-1140)2	1329(987-1530)4	1073(600-1640)10	1420(961-1880)2	702(607-796)2	--
3355	479(220-887)6	1415(1400-1430)2	1101(926-1330)5	1141(517-2120)10	990(469-1510)2	1259(698-1600)3	1062(434-1690)2	--
3360	-	1250(-)1	1350(1090-1610)2	1429(888-1970)2	1600(-)1	1900(-)1	--	--
3370	884(549-1220)2	1152(422-1480)9	--	1492(883-2730)10	1180(368-1880)9	1226(549-1940)11	1098(530-1600)10	553(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-2. CONDUCTIVITY (μmho/cm at 25°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	1867(1450-2450)9	1555(967-2250)16	--	--	--	--	--
3346	--	1626(891-2290)11	1395(624-2340)20	--	--	--	--	--
3350	1300(930-1570)3	1595(216-2360)13	1323(630-1750)16	1657(1070-2450)12	1665(924-2600)12	1622(610-2500)14	1347(890-2200)13	1128(261-2000)11
3355	823(350-1460)9	1682(250-2540)14	1354(660-1880)15	1809(750-3600)13	1895(635-3800)14	1777(630-3550)16	1566(600-3150)16	1200(262-2350)10
3360	977(510-1640)3	1645(376-2700)13	1623(560-2280)15	2032(860-4200)13	1550(640-2500)12	2600(-)1	--	--
3370	1098(740-1740)3	1689(635-2610)13	1749(1080-2520)11	2092(940-5000)13	1777(790-2700)9	1668(840-2200)11	1442(720-2050)13	544(400-820)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-3. DISSOLVED CALCIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	105(85-140)9	95(50-140)16	--	--	--	--	--
3346	--	38(26-53)11	46(23-89)20	--	--	--	--	--
3350	--	86(-)1	52(45-60)2	70(45-120)4	52(37-83)10	54(52-57)2	38(31-44)2	--
3355	40(22-67)6	67(61-73)2	65(48-76)5	44(21-72)10	36(35-38)2	46(39-55)3	47(44-50)2	--
3360	--	92(-)1	64(49-80)2	64(51-78)2	64(-)1	75(-)1	--	--
3370	70(55-85)2	74(48-100)9	--	76(41-140)10	68(24-110)9	72(28-130)11	60(31-94)10	38(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-4. DISSOLVED SODIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	269(190-360)9	204(92-340)16	--	--	--	--	--
3346	--	309(130-460)11	235(67-490)20	--	--	--	--	--
3350	--	370(-)1	255(240-270)2	335(250-390)4	257(130-400)10	370(240-500)2	170(120-220)2	--
3355	92(35-190)6	325(290-360)2	254(190-330)5	294(120-610)10	256(91-420)2	340(130-460)3	260(71-450)2	--
3360	--	243(-)1	305(250-360)2	355(700-510)2	400(-)1	500(-)1	--	--
3370	176(93-260)2	247(66-330)9	--	368(210-710)10	278(83-450)9	279(140-430)11	266(110-390)10	100(-)1

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-5. DISSOLVED MAGNESIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	46(37-65)9	41(21-62)16	--	--	--	--	--
3346	--	28(16-41)11	29(11-71)20	--	--	--	--	--
3350	--	79(-)1	42(38-45)2	34(12-47)4	38(24-59)10	43(36-50)2	22(18-27)2	--
3355	17(8-30)6	46(45-48)2	34(24-39)5	30(16-47)10	26(16-35)2	29(25-35)3	24(15-33)2	--
3360	--	48(-)1	46(31-60)2	36(23-50)2	41(-)1	44(-)1	--	--
3370	29(19-39)2	36(15-54)9	--	39(16-61)10	32(12-57)9	36(12-60)11	26(11-41)10	25(-)1

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-6. DISSOLVED POTASSIUM (mg/1), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	10.6(8.5-13.0)9	10.2(7.2-15.0)16	--	--	--	--	--
3346	--	6.0(5.2-7.9)11	6.2(4.6-9.3)20	--	--	--	--	--
3350	--	5.8(-)1	5.8(5.1-6.5)2	5.6(4.2-7.7)4	6.1(4.9-8.0)10	8.4(6.9-10.0)2	5.4(4.7-6.0)2	--
3355	6.4(4.6-7.7)6	6.6(6.4-6.8)2	6.7(4.7-8.8)5	7.9(4.9-16.0)10	6.4(4.4-8.5)2	9.6(8.3-12.0)3	9.0(4.9-13.0)2	--
3360	--	7.3(-)1	9.4(7.8-11.0)2	4.4(1.8-7.1)2	7.3(-)1	9.6(-)1	--	--
3370	8.0(6.8-9.2)2	8.3(5.5-11.0)9	--	11.2(7.4-17.0)10	9.6(5.6-13.0)9	10.9(9.1-14.0)11	9.1(4.8-13.0)10	7.3(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-7. BICARBONATE ION (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	348(227-509)9	252(75-449)16	--	--	--	--	--
3346	--	476(171-808)11	350(122-795)20	--	--	--	--	--
3350	--	71(-)1	468(442-494)2	498(400-660)4	427(70-724)10	435(427-443)2	261(255-267)2	--
3355	140(86-311)6	330(124-535)2	366(249-520)5	292(109-580)10	282(118-445)2	402(234-558)3	218(119-317)2	--
3360	--	316(-)1	272(130-413)2	261(127-395)2	331(-)1	443(-)1	--	--
3370	223(149-298)2	305(156-432)9	--	414(196-947)10	324(127-589)9	373(198-648)11	300(130-470)10	160(-)1

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-8. SULFATE ION (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	761(590-1000)9	639(400-950)16	--	--	--	--	--
3346	--	457(270-620)11	449(190-940)20	--	--	--	--	--
3350	--	1230(-)1	450(400-500)2	615(420-810)4	490(240-720)10	690(380-1000)2	320(270-370)2	--
3355	238(93-440)6	775(650-900)2	538(430-670)5	590(280-1100)10	510(250-770)2	597(340-730)3	590(230-950)2	--
3360	--	687(1)1	765(660-870)2	815(530-1100)2	900(-)1	1000(-)1	--	--
3370	470(290-650)2	613(200-830)9	--	768(480-1300)10	610(170-920)9	624(250-970)11	566(290-820)10	290(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-9. CHLORIDE (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	15.8(8.6-26.0)9	9.8(3.3-18.0)16	--	--	--	--	--
3346	--	16.3(5.2-37.0)11	15.0(4.5-45.0)20	--	--	--	--	--
3350	--	13.0(-)1	7.6(5.7-9.4)2	8.5(5.6-13.0)4	7.7(4.2-9.5)10	10.2(7.5-13.0)2	8.0(4.0-12.0)2	--
3355	7.6(1.4-25.0)6	18.4(6.8-30.0)2	11.8(7.5-19.0)5	10.5(5.7-19.0)10	12.3(5.6-19.0)2	12.0(5.9-16.0)3	10.4(2.9-18.0)2	--
3360	--	7.0(-)1	16.0(15.0-17.0)2	12.7(3.4-22.0)2	20.0(-)1	18.0(-)1	--	--
3370	12.4(2.9-22.0)2	7.4(0-15.0)9	--	11.3(4.8-22.0)10	10.8(4.4-33.0)9	9.8(4.5-18.0)11	9.1(4.6-16.0)10	5.8(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-10. DISSOLVED SILICA (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	7.4(3.0-11.0)9	7.4(2.9-15.0)16	--	--	--	--	--
3346	--	8.6(6.3-11.0)11	8.6(5.7-12.0)20	--	--	--	--	--
3350	--	9.4(-)1	8.5(5.0-12.0)2	5.0(2.9-7.1)4	5.8(1.5-11.0)10	6.8(1.5-12.0)2	8.2(6.9-9.5)2	--
3355	6.9(4.7-9.3)6	8.2(7.4-9.1)2	7.7(4.8-11.0)5	5.5(2.4-8.6)10	1.6(1.3-2.0)2	5.5(1.9-9.9)3	4.8(3.0-6.5)2	--
3360	--	6.8(-)1	7.5(5.2-9.8)2	7.7(7.1-8.3)2	2.4(-)1	6.1(-)1	--	--
3370	8.6(7.7-9.4)2	9.5(7.6-11.0)9	--	9.9(6.5-14.0)10	8.5(5.3-11.0)9	8.6(5.8-12.0)11	8.6(5.3-12.0)10	7.5(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-11. TOTAL HARDNESS (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	450(360-620)9	412(210-610)16	--	--	--	--	--
3346	--	207(150-260)11	234(100-510)20	--	--	--	--	--
3350	--	540(-)1	305(270-340)2	315(240-350)4	289(190-450)10	315(280-350)2	185(150-220)2	--
3355	171(87-290)6	340(300-380)2	302(220-350)5	233(120-340)10	195(160-230)2	223(200-250)3	215(170-260)2	--
3360	--	430(-)1	350(250-450)2	310(220-400)2	330(-)1	370(-)1	--	--
3370	295(220-370)2	334(180-450)9	--	350(170-600)10	302(110-510)9	328(120-570)11	257(120-400)10	200(-)1

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-12. TEMPERATURE (C°) 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	9.3(0-20.0)3	13.1(0-22.0)8	--	5.3(0.5-9.5)3	11.2(0-28.5)10	10.8(0-21.0)9	--
3346	--	9.6(0-20.0)6	9.8(0.5-22.5)6	--	--	--	--	--
3350	3.0(0-8.0)3	7.2(0-22.0)14	8.9(0-24.5)16	9.0(0-28.0)14	8.6(0-22.0)12	8.6(0-24.0)14	7.1(0-20.0)14	5.8(0-24.0)11
3355	5.2(0-15.5)5	8.5(0-24.0)14	11.7(0.5-25.0)15	10.8(0-30.0)13	10.6(0-29.0)14	10.3(0-27.0)16	10.2(0-26.0)16	6.8(0-28.0)10
3360	4.0(0-11.0)3	6.9(0-25.0)18	10.4(0-27.0)15	9.6(0-30.5)13	12.0(1.0-27.0)12	0(-)1	--	--
3370	2.9(0-10.0)8	9.0(0-24.0)31	12.3(0-27.0)21	9.5(0-24.5)13	10.4(0-22.0)9	11.0(0-23.0)11	11.0(0-24.5)13	4.7(1.0-9.0)5

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-13. pH, 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	8.0(7.5-8.3)9	8.0(7.7-8.3)16	--	--	--	--	--
3346	--	8.0(7.5-8.4)11	7.8(7.4-8.3)20	--	--	--	--	--
3350	--	7.3(-)1	8.2(8.2-8.3)2	8.4(8.4-8.5)4	8.3(8.0-8.7)10	8.6(8.5-8.8)2	8.5(8.5-8.5)2	--
3355	7.2(6.9-7.9)6	7.8(7.4-8.2)2	8.2(8.0-8.3)5	8.1(7.1-8.5)10	8.4(8.1-8.6)2	8.6(8.4-8.8)3	8.5(8.5-8.5)2	--
3360	--	8.1(-)1	8.1(8.0-8.3)2	8.0(7.8-8.3)2	8.5(-)1	8.4(-)1	--	--
3370	7.8(7.5-8.0)2	7.7(7.3-8.0)9	--	8.4(7.9-8.6)10	8.3(7.9-8.6)9	8.5(7.8-8.9)11	8.4(8.2-8.6)10.0	8.3(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-14. TOTAL ALKALINITY ($CaCO_3$, mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3340	--	--	--	--	--	--	--	--
3345	--	286(186-417)9	207(62-368)16	--	--	--	--	--
3346	--	392(140-663)11	287(100-652)20	--	--	--	--	--
3350	--	58(-)1	390(374-405)2	421(340-541)4	352(65-594)10	387(374-400)2	216(212-219)2	--
3355	115(71-255)6	270(102-439)2	302(204-427)5	252(89-487)10	232(97-368)2	360(197-498)3	194(98-290)2	--
3360	--	259(-)1	227(107-347)2	214(104-324)2	272(-)1	400(-)1	--	--
3370	182(121-244)2	250(128-354)9	--	347(161-777)10	272(104-483)9	300(162-531)10	251(110-390)10	130(-)1

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-15. DISSOLVED SOLIDS, SUM OF CONSTITUENTS (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	4000(3880-4120)2	4412(2900-7870)4	2585(1130-3100)4	1050(809-1290)2
42578	--	--	--	--	3690(-)1	2117(1240-3000)7	1453(182-2970)8	1441(751-2820)3
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	350(-)1	1384(460-2630)5
4265	--	--	--	--	1621(544-2150)5	1456(290-3050)11	1311(617-2700)10	1547(379-2540)5
4278	1185(449-1740)11	1134(520-1700)12	1092(564-1470)12	1062(520-1550)12	1060(554-1470)12	1091(628-1530)12	1126(635-1630)13	1176(417-1610)3
4285	1199(428-2290)11	1367(634-2080)12	1102(620-1650)12	1307(706-2160)12	1381(863-2070)11	1387(928-2120)11	1363(686-2010)16	1495(440-1880)4
4295	--	--	--	224(-)1	--	--	--	--
4299	--	--	--	496(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	878(465-1000)10	894(589-1180)16	891(570-1030)13	974(532-1560)9	908(635-1050)11	969(869-1170)12	899(615-1090)11	702(354-1040)4
4367	--	--	--	964(-)1	--	--	--	--
4368	1924(660-4260)10	3004(973-5820)17	2657(1490-4740)18	3554(1360-5640)11	2830(594-5510)11	3405(760-6520)13	3351(815-6190)12	4188(394-6140)3
4370	1396(466-2490)13	1687(761-3250)17	1519(714-3220)21	1835(945-3450)11	1714(924-2890)11	1716(462-2900)13	1914(585-2980)10	1735(443-3010)5
4380	--	2068(1370-3100)5	1472(1050-2920)9	2330(1910-3070)3	1726(734-3360)12	1702(677-3080)12	1809(670-3670)13	1603(401-2640)4

*For full description of station locations, see Table 26.
[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-16. CONDUCTIVITY (µmho/cm at 25°C), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max)n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	5100(5000-5200)2	4940(3600-8000)5	3175(1100-4000)4	2217(1100-3800)3
42578	--	--	--	--	5000(-)1	2675(650-4200)8	1660(300-2600)8	2075(1100-3100)4
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	2668(1830-3300)4	2014(740-3750)5
4265	--	--	--	--	2258(690-3500)5	2114(480-4000)11	1726(950-3800)10	2250(610-3500)7
4278	1477(627-2100)11	1448(793-2060)12	1413(881-1820)12	1432(828-1910)12	1481(830-1900)12	1421(890-1900)12	1470(910-2400)11	770(-)1
4285	1510(580-2900)15	1716(938-2360)16	1394(894-1970)15	1464(1020-2470)9	1617(1350-2000)3	1625(1450-1900)4	1726(1000-2400)7	1324(570-2200)5
4295	--	--	--	395(-)1	--	--	--	--
4299	--	--	--	772(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	1150(684-1400)16	1187(850-1460)16	1197(845-1320)13	1359(800-1970)9	1270(980-1500)11	1270(1100-1500)12	1239(800-1500)10	1135(685-1650)4
4367	--	--	--	1560(-)1	--	--	--	--
4368	2406(622-5910)17	3524(1390-6320)17	3150(1940-5680)18	4268(1850-7000)11	3472(735-6400)12	3488(1260-5900)13	3758(1440-7200)12	4893(580-7100)3
4370	1675(743-2880)20	2082(1080-3780)17	1913(1000-3900)21	2413(1210-5200)11	2255(1290-3950)11	2091(750-3600)13	2468(875-4000)10	2344(680-3500)5
4380	2115(712-4420)20	2526(888-4200)13	1933(990-4150)19	3130(2840-3620)3	2227(1280-4000)12	1885(390-3420)12	2308(1150-4300)13	2200(700-3500)4

---

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-17. DISSOLVED CALCIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	370(370-370)2	390(310-530)4	280(120-340)4	122(95-150)2
42578	--	--	--	--	380(-)1	230(150-340)7	180(32-370)8	169(82-340)3
4259	--	--	--	--	--	--	--	916(13-180)2
4264	--	--	--	--	--	--	146(77-190)3	108(45-180)5
4265	--	--	--	--	68(30-130)5	92(39-220)11	97(56-180)10	108(44-160)5
4278	203(67-310)11	180(62-290)12	178(61-270)12	164(53-260)12	165(64-230)12	178(69-270)12	176(57-280)13	207(62-300)3
4285	202(88-410)11	230(90-410)12	183(100-300)12	213(99-370)12	244(120-420)11	234(130-380)11	212(71-350)16	262(60-370)4
4295	--	--	--	55(-)1	--	--	--	--
4299	--	--	--	120(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	160(93-200)16	172(99-260)16	174(110-210)3	186(96-260)9	173(110-210)11	201(160-240)12	180(96-230)11	142(64-220)4
4367	--	--	--	200(-)1	--	--	--	--
4368	177(42-360)17	249(86-430)17	227(130-350)18	285(200-450)11	244(56-440)11	273(84-440)13	270(78-430)12	284(43-410)3
4370	169(78-250)20	214(90-380)17	208(120-400)21	238(140-420)11	223(89-360)11	228(71-370)13	239(81-390)10	217(53-340)5
4380	210(80-510)12	236(77-370)10	196(130-300)9	293(250-380)3	222(83-370)12	212(100-360)12	221(70-430)13	199(50-330)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-18. DISSOLVED SODIUM (mg/1), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	515(510-520)2	600(350-1200)4	310(120-410)4	135(100-170)2
42578	--	--	--	--	470(-)1	254(140-350)7	164(13-330)8	173(100-320)3
4259	--	--	--	--	--	--	--	282(13-550)2
4264	--	--	--	--	--	--	350(250-430)3	246(47-530)5
4265	--	--	--	--	412(100-580)5	320(40-630)1	260(97-550)10	316(570)5
4278	76(29-100)11	79(50-110)12	79(50-98)12	93(40-150)12	86(27-130)12	88(48-140)12	103(34-140)13	89(27-120)3
4285	77(17-140)11	89(55-120)12	72(37-96)12	94(50-140)12	89(40-130)11	99(59-140)11	117(54-150)16	107(39-130)4
4295	--	--	--	1(-)1	--	--	--	--
4299	--	--	--	3(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	38(13-68)16	35(19-66)16	34(20-51)13	45(22-100)9	41(18-76)11	33(11-72)12	38(17-96)11	28(20-36)4
4367	--	--	--	24(-)1	--	--	--	--
4368	252(30-770)17	402(120-830)17	355(130-700)18	488(110-940)11	382(88-800)11	462(96-1000)13	470(92-1000)12	635(56-950)3
4370	112(26-260)20	148(72-340)17	124(46-280)21	159(63-360)11	145(49-280)11	147(36-280)13	172(44-300)10	164(43-280)5
4380	181(29-410)4	181(88-310)7	128(69-320)9	223(180-310)3	158(64-330)12	160(42-280)12	174(67-370)13	174(48-280)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-19. DISSOLVED MAGNESIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	240(230-250)2	268(160-530)4	145(70-190)4	50(35-65)2
42578	--	--	--	--	210(-)1	112(64-170)7	82(9-170)8	78(36-160)3
4259	--	--	--	--	--	--	--	108(7-210)2
4264	--	--	--	--	--	--	116(67-150)3	79(33-130)5
4265	--	--	--	--	50(23-77)5	53(13-120)11	56(12-130)10	71(23-110)5
4278	57(20-80)11	60(25-95)12	57(25-82)12	52(14-78)12	53(26-79)12	51(25-74)12	54(27-78)13	53(27-69)3
4285	59(19-110)11	67(31-120)12	56(34-93)12	65(29-110)12	61(38-110)11	63(41-95)11	64(33-110)16	59(24-83)4
4295	--	--	--	20(-)1	--	--	--	--
4299	--	--	--	29(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	43(21-53)16	45(27-61)16	47(31-53)13	41(25-79)9	47(32-60)11	49(41-63)12	45(29-54)11	36(17-55)4
4367	--	--	--	54(-)1	--	--	--	--
4368	123(21-170)17	191(53-390)17	167(84-330)18	235(75-380)11	178(34-350)11	218(39-430)13	220(46-420)12	279(18-410)3
4370	76(25-160)20	104(39-210)17	92(40-210)21	117(50-230)11	104(54-180)11	106(22-200)13	122(37-210)10	113(21-200)5
4380	97(12-260)12	113(27-200)10	85(53-180)9	153(120-210)3	106(36-230)12	103(32-190)12	116(28-240)13	99(16-180)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-20. DISSOLVED POTASSIUM (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	31.5(23.0-40.0)2	24.2(17.0-45.0)4	12.0(8.9-15.0)4	8.0(6.4-9.6)2
42578	--	--	--	--	30.0(-)1	17.0(12.0-19.0)7	12.4(5.8-19.0)8	11.2(6.6-20.0)3
4259	--	--	--	--	--	--	--	10.9(6.8-15.0)2
4264	--	--	--	--	--	--	15.0(11.0-22.0)3	13.4(8.0-19.0)5
4265	--	--	--	--	10.7(7.7-13.0)5	10.6(8.2-16.0)11	11.4(7.7-18.0)10	12.5(6.0-17.0)5
4278	6.8(5.1-8.1)11	7.3(5.8-8.4)12	6.6(5.1-7.2)12	7.1(5.8-9.3)12	7.0(6.1-7.9)12	7.0(4.9-8.8)12	7.1(4.4-8.8)13	4.2(0.2-6.6)3
4285	7.3(3.1-9.5)11	8.0(6.3-9.5)12	7.3(5.8-8.4)12	8.0(6.3-9.5)12	8.2(6.5-9.8)11	8.2(5.6-9.3)11	8.1(4.2-10.0)16	6.9(5.6-8.5)4
4295	--	--	--	0.7(-)1	--	--	--	--
4299	--	--	--	1.4(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	5.4(3.6-7.6)16	4.8(3.3-6.8)16	4.6(3.5-6.4)13	5.6(3.3-11.0)9	5.1(3.0-8.0)11	4.8(2.7-8.4)12	4.5(3.3-8.2)11	5.1(3.2-8.5)4
4367	--	--	--	3.4(-)1	--	--	--	--
4368	9.1(5.8-20.0)17	9.8(5.8-14.0)17	10.1(6.9-14.0)18	11.6(9.4-16.0)11	10.0(4.7-14.0)11	11.2(6.8-18.0)13	9.8(0.9-18.0)12	11.0(4.9-14.0)3
4370	14.0(7.8-30.0)20	14.1(8.8-20.0)17	14.3(5.7-34.0)21	17.8(11.0-30.0)11	15.1(11.0-22.0)11	15.4(7.0-28.0)13	15.0(11.0-18.0)10	10.1(5.5-15.0)5
4380	17.0(8.8-34.0)4	13.8(8.6-17.0)7	12.2(8.6-20.0)9	20.3(16.0-25.0)3	14.9(7.5-24.0)12	14.6(8.5-22.0)12	15.3(9.6-21.0)13	10.9(5.8-15.0)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-21. BICARBONATE ION (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$(min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	316(222-410)2	302(225-362)4	259(110-370)4	135(110-160)2
42578	--	--	--	--	356(-)1	229(106-386)7	269(63-520)8	253(120-500)3
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	520(360-601)4	384(90-739)5
4265	--	--	--	--	542(169-678)5	464(99-820)11	378(160-705)10	442(92-780)5
4278	222(92-342)11	227(113-352)12	220(155-289)12	252(186-365)12	228(140-350)12	233(130-320)12	237(170-330)13	193(110-310)3
4285	183(49-348)11	207(146-323)12	182(115-246)12	211(122-378)12	222(130-330)11	216(170-280)11	204(79-340)16	227(128-310)4
4295	--	--	--	262(-)1	--	--	--	--
4299	--	--	--	276(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	189(129-231)16	218(146-284)16	220(188-286)13	225(147-310)9	214(153-291)11	232(187-289)12	226(190-297)11	182(73-280)4
4367	--	--	--	297(-)1	--	--	--	--
4368	205(101-400)16	293(127-561)17	245(173-387)18	332(188-593)11	278(94-526)11	310(135-366)13	338(100-706)12	383(69-550)3
4370	191(148-294)20	237(129-425)17	233(174-493)21	271(164-561)11	255(114-434)11	260(147-431)13	268(140-467)10	240(80-390)5
4380	254(128-601)4	282(163-441)7	210(128-365)9	270(209-376)3	235(96-499)12	215(161-376)12	233(88-501)13	220(81-390)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-22. SULFATE (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	2650(2500-2800)2	2950(1900-5400)4	1688(750-2000)4	660(510-810)2
42578	--	--	--	--	2400(-)1	1371(730-1900)7	867(85-1800)8	867(440-1700)3
4259	--	--	--	--	--	--	--	972(43-1900)2
4264	--	--	--	--	--	--	927(580-1200)3	638(220-1200)5
4265	--	--	--	--	786(260-1100)5	719(130-1600)11	636(290-1300)10	710(200-1100)5
4278	719(260-1100)11	679(260-1000)12	646(290-890)12	607(250-900)12	622(270-890)12	636(310-910)12	645(290-960)13	707(230-950)3
4285	744(233-1400)11	847(340-1300)12	672(340-1000)12	807(430-1300)12	743(130-1300)11	859(510-1300)11	845(340-1200)16	882(230-1100)4
4295	--	--	--	4(-)1	--	--	--	--
4299	--	--	--	190(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	489(290-600)16	512(330-680)16	506(290-590)13	560(290-1000)9	521(350-620)11	552(480-720)12	503(320-610)11	385(190-580)4
4367	--	--	--	502(-)1	--	--	--	--
4368	1224(200-3300)17	1903(590-3700)17	1693(930-3000)18	2261(840-3600)11	1796(340-3500)11	2157(440-4300)13	2092(500-3700)12	2640(220-3900)3
4370	786(240-1600)20	1049(450-2000)17	930(390-2000)21	1125(550-2100)11	1046(560-1800)11	1052(240-1800)13	1186(320-1800)10	1062(250-1900)5
4380	1084(260-2600)12	1137(350-1900)10	909(640-1800)9	1467(1200-1900)3	1080(440-2100)12	1078(400-2000)12	1135(410-2300)13	975(230-1600)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-23. CHLORIDE (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	34(29-38)2	30(19-55)4	17(9-22)4	5(4-6)2
42578	--	--	--	--	22(-)1	12(8-20)7	9(2-14)8	9(4-15)3
4259	--	--	--	--	--	--	--	8(2-13)2
4264	--	--	--	--	--	--	154(63-230)3	98(23-190)5
4265	--	--	--	--	17(14-19)5	24(6-53)11	56(6-170)10	100(10-180)5
4278	6(3-10)11	6(2-8)12	7(5-10)12	7(4-13)12	7(4-11)12	9(4-21)12	13(5-30)13	8(6-10)3
4285	6(3-10)12	6(3-10)12	6(4-9)12	6(4-11)12	8(4-11)11	10(5-27)11	12(4-32)16	11(5-13)4
4295	--	--	--	1(-)1	--	--	--	--
4299	--	--	--	3(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	5(3-8)16	4(3-9)16	5(2-10)13	5(4-9)9	5(3-8)11	5(3-10)12	6(3-12)11	4(3-6)4
4367	--	--	--	4(-)1	--	--	--	--
4368	41(8-130)17	73(18-160)17	56(10-120)18	74(16-190)11	60(4-120)11	84(15-230)13	81(15-190)12	106(9-160)3
4370	16(4-39)20	21(7-50)17	17(6-42)21	22(8-50)11	25(9-62)11	19(4-35)13	26(9-46)10	26(6-42)5
4380	23(5-60)12	23(7-41)10	18(10-61)9	31(22-48)3	22(9-48)12	24(6-41)12	26(10-58)13	28(6-48)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-24. DISSOLVED SILICA (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	5.0(1.2-8.8)2	4.2(0.3-7.3)4	5.1(0.2-7.1)4	4.1(3.9-4.3)2
42578	--	--	--	--	5.9(-)1	4.0(0.3-8.4)7	4.5(0.4-8.8)8	6.9(4.4-11.0)3
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	5.7(3.9-9.2)3	11.2(6.0-18.0)5
4265	--	--	--	--	8.5(8.0-9.6)5	7.1(3.7-11.0)11	6.6(3.8-11.0)10	10.4(5.9-16.0)5
4278	7.5(0.9-11.0)11	7.3(2.6-11.0)12	6.6(0.5-11.0)12	6.5(0.7-11.0)12	6.4(0.3-10.0)12	5.2(0-10.0)12	6.9(1.0-17.0)13	9.7(6.1-13.0)3
4285	8.8(4.6-11.0)12	10.1(5.5-13.0)12	8.8(5.7-11.0)2	8.5(3.7-15.0)12	7.9(3.7-11.0)11	7.1(4.0-11.0)11	7.1(3.4-12.0)16	11.5(8.9-13.0)4
4295	--	--	--	13.0(-)1	--	--	--	--
4299	--	--	--	12.0(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	9.2(5.6-12.0)10	10.5(5.0-17.0)16	11.4(8.7-17.0)13	7.6(2.0-12.0)9	9.2(6.9-12.0)11	8.3(5.9-10.0)12	8.6(5.4-10.0)11	8.6(5.6-11.0)4
4367	--	--	--	10.0(-)1	--	--	--	--
4368	6.9(3.4-8.2)10	5.9(2.4-11.0)17	5.5(1.2-14.0)18	4.4(0.9-9.2)11	5.0(1.5-8.9)11	4.3(0.9-8.8)13	5.7(2.3-8.4)12	5.5(1.4-9.3)3
4370	7.8(6.0-10.0)13	7.4(4.6-11.0)17	8.2(4.4-13.0)21	7.6(2.4-12.0)11	7.3(4.0-11.0)11	6.6(5.3-9.0)13	7.4(5.7-9.6)10	9.0(5.2-11.0)5
4380	--	5.3(3.8-6.9)5	6.9(3.8-8.3)9	6.2(5.1-7.1)3	6.8(3.6-10.0)12	5.3(4.0-8.0)12	6.5(4.4-9.2)13	7.8(4.6-10.0)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-25. TOTAL HARDNESS (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	1950(1900-2000)2	2050(1400-3500)4	1298(590-1600)4	510(380-640)2
42578	--	--	--	--	1800(-)1	1037(640-1600)7	791(120-1600)8	737(350-1500)3
4259	--	--	--	--	--	--	--	680(61-1300)2
4264	--	--	--	--	--	--	843(470-1100)3	596(250-980)5
4265	--	--	--	--	376(210-640)5	444(150-1000)11	474(200-980)10	562(200-850)5
4278	745(280-1100)11	699(260-1100)12	862(260-930)12	927(240-980)12	634(270-880)12	652(270-970)12	632(250-1000)13	727(270-1000)3
4285	747(300-1400)11	847(350-1400)12	693(400-1100)12	807(380-1400)12	865(460-1300)11	841(490-1400)11	870(320-1300)16	912(250-1200)4
4295	--	--	--	202(-)1	--	--	--	--
4299	--	--	--	420(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	575(320-720)16	614(360-900)16	626(400-740)13	676(340-970)9	628(410-730)11	704(570-800)12	638(360-800)11	502(230-780)4
4367	--	--	--	720(-)1	--	--	--	--
4368	942(190-2400)17	1414(430-2700)17	1250(770-2200)18	1674(810-2400)11	1344(280-2500)11	1582(370-2700)13	1592(380-2800)12	1860(180-2700)3
4370	742(300-1300)20	964(390-1800)17	899(460-1900)21	1075(560-2000)11	981(450-1600)11	993(270-1700)13	1100(360-1800)10	1028(220-1700)5
4380	1044(300-2400)7	1051(300-1700)10	841(540-1500)9	1367(1100-1800)3	992(360-1900)12	959(380-1700)12	1030(290-2100)13	908(190-1600)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-26. TOTAL IRON (µg/l), 1972-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1972†	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	340(-)1	2180(840-4700)3	450(440-460)2	870(860-880)2
42578	--	--	--	370(-)1	534(120-1700)5	9078(420-33,000)4	1315(630-20000)2
4259	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	--
4265	--	--	--	5035(770-9300)2	3540(460-8100)4	1195(260-2000)4	450(-)1
4278	--	--	--	895(190-1600)2	645(170-1500)4	1027(80-1600)3	--
4285	--	--	--	--	--	880(-)1	37,000(-)1
4295	--	--	--	--	--	--	--
4299	--	--	--	--	--	--	--
4305	--	--	--	--	--	--	--
4345	--	--	--	--	--	--	--
4367	--	--	--	--	--	--	--
4368	--	--	--	--	--	--	--
4370	--	--	--	--	--	--	--
4380	--	--	300(-)1	72,367(1100-200,000)3	263,400(200-740,000)3	205,823(190-460,000)4	240(-)1

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-27. TOTAL MANGANESE (μg/l) 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$(min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	90(-)1	970(510-1400)3	215(210-220)2	260(250-270)2
42578	--	--	--	--	2600(-)1	596(50-2400)5	305(80-430)4	1110(220-2000)2
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	350(-)1	--
4265	--	--	--	--	250(250-250)2	492(110-1000)4	245(140-410)4	1900(-)1
4278	--	--	--	--	190(70-310)2	130(50-240)4	117(50-190)3	--
4285	--	--	--	--	--	--	140(-)1	2000(-)1
4295	--	--	--	--	--	--	--	--
4299	--	--	--	--	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	--	--	--	--	--	--	--	--
4367	--	--	--	--	--	--	--	--
4368	--	--	--	--	--	--	--	--
4370	--	--	--	--	--	--	--	--
4380	--	--	--	170(-)1	913(150-2100)3	7855(160-29,000)4	5635(140-13,000)4	500(-)1

---

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-28. TEMPERATURE (C°), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	5.0(4.0-6.0)2	7.5(0-25.0)12	14.5(0-24.0)5	16.8(14.0-22.5)3
42578	--	--	--	--	2.5(-)1	11.1(0-32.0)15	11.3(0-27.0)9	13.2(0-25.0)4
4259	--	--	--	--	--	--	--	1.5(-)1
4264	--	--	--	--	--	--	6.6(0-14)4	2.7(0-7.8)6
4265	--	--	--	--	21.2(3.0-31.0)5	10.0(0-28.0)17	11.7(0-25.0)14	8.4(0-19.0)7
4278	10.0(0-21.5)11	10.0(0-24.5)12	8.4(0-24.0)12	9.2(0-19.5)13	10.3(0-27.0)12	10.3(0-28.0)12	7.8(0-21.5)14	6.4(0-14.0)5
4285	10.2(0-24.5)16	8.1(0-22.0)16	9.7(0-22.5)15	9.8(0-23.5)12	8.6(0-29.0)13	11.5(0-25.5)24	8.8(0-23.0)24	6.7(0-18.0)6
4295	--	--	--	11.5(-)1	4.2(0-9.5)4	7.0(0.5-16.5)12	7.3(0-15.0)9	--
4299	--	--	--	12.5(-)1	10.8(9.5-12.5)3	14.2(9.5-26.0)11	--	--
4305	8.5(3.0-14.0)4	9.5(0-18.0)11	9.4(2.0-18.0)11	9.8(0-18.0)12	8.3(1.0-18.5)16	10.5(0.5-20.5)23	12.0(0.5-24.5)18	--
4345	14.6(0-25.5)5	7.5(0-20.0)4	12.6(0-19.5)7	11.9(0-28.0)9	12.7(0-28.0)10	10.9(0-22.5)12	10.0(0-21.0)11	1.2(0-2.5)4
4367	--	--	--	0(-)1	--	17.0(0.5-27.5)3	--	--
4368	13.1(0-22.5)5	7.2(0-20.0)5	12.0(0-24.0)10	12.1(0-26.0)11	11.1(0-26.5)11	11.9(0-27.0)13	10.7(0-24.5)12	3.8(0-11.0)3
4370	14.6(0-25.0)8	7.2(0-24.5)6	10.7(0-26.0)12	10.7(0-25.0)11	13.0(0-25.5)10	10.5(0-24.5)13	9.7(0-23.0)10	5.0(0-19.5)5
4380	10.0(0-26.0)27	7.7(0-20.0)22	12.2(0-27.0)19	5.0(0.5-9.0)3	10.0(0-25.5)12	9.5(0-24.0)15	11.0(0-25.5)23	2.9(0-7.0)4

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-29. DISSOLVED OXYGEN (mg/1), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	10.3(8.8-11.8)2	9.7(9.1-10.0)4	8.6(6.3-11.0)4	9.9(8.2-12.0)3
42578	--	--	--	--	6.5(-)1	9.4(4.3-11.9)7	10.2(6.8-17.4)8	9.1(8.8-9.3)4
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	10.2(4.8-15.2)4	9.6(7.6-11.3)5
4265	--	--	--	--	8.0(5.4-10.6)5	7.9(4.7-12.6)11	9.2(7.0-11.2)10	8.8(7.6-11.0)7
4278	--	--	11.8(11.6-12.0)2	8.7(6.8-11.2)13	9.5(6.9-12.0)12	9.6(7.1-12.0)12	9.6(7.4-11.2)10	--
4285	9.4(8.0-10.2)4	10.4(8.8-12.7)4	9.8(7.5-12.4)4	8.2(7.2-9.5)4	10.4(6.4-11.8)4	9.5(7.3-10.6)4	10.8(7.9-12.8)7	10.4(7.8-13.2)5
4295	--	--	--	--	--	--	--	--
4299	--	--	--	--	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	--	--	--	--	--	--	--	--
4367	--	--	--	--	--	--	--	--
4368	--	--	--	--	--	--	--	--
4370	--	--	--	--	--	--	--	--
4380	9.1(6.1-12.9)11	9.4(7.5-12.7)10	9.5(7.8-12.6)10	--	--	--	9.9(-)1	8.5(7.6-9.6)3

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-30. pH, 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	7.9(7.7-8.1)2	7.8(7.3-8.4)4	7.9(7.6-8.4)4	7.9(7.5-8.1)3
42578	--	--	--	--	7.4(-)1	8.0(7.3-8.7)7	7.8(7.4-8.2)8	7.8(7.3-8.4)4
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	8.0(7.6-8.4)4	7.7(7.3-8.1)5
4265	--	--	--	--	8.0(7.6-8.3)5	7.7(7.3-8.3)11	8.1(7.7-8.6)10	7.6(6.7-8.2)7
4278	7.8(7.5-8.2)11	7.8(7.5-8.1)12	8.0(7.7-8.3)12	8.0(6.8-8.4)12	8.0(7.6-8.2)12	7.9(7.5-8.2)12	8.0(7.7-8.4)9	8.2(-)1
4285	7.7(6.6-8.2)15	7.9(7.4-8.3)16	8.0(7.6-8.3)15	8.0(7.7-8.3)9	7.4(-)1	--	7.8(7.4-8.1)4	7.6(7.3-8.2)5
4295	--	--	--	--	--	--	--	--
4299	--	--	--	--	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	7.8(7.4-8.2)16	7.9(7.4-8.2)16	8.0(7.6-8.2)13	7.9(7.5-8.1)6	8.2(8.0-8.5)9	8.1(7.5-8.5)11	8.1(7.3-8.4)11	7.9(7.8-8.0)4
4367	--	--	--	--	--	--	--	--
4368	7.8(7.5-8.4)17	7.9(7.5-8.3)17	8.0(7.6-8.3)18	8.0(7.6-8.3)8	8.0(7.6-8.8)11	7.9(7.2-8.6)13	8.0(7.3-8.5)12	7.7(7.6-7.8)3
4370	7.7(7.2-8.1)20	7.9(7.3-8.2)17	8.0(7.7-8.2)21	7.9(7.5-8.1)8	8.1(7.1-8.7)10	8.0(7.4-8.8)12	8.0(7.3-8.3)10	7.8(7.6-8.0)4
4380	7.9(7.4-8.6)22	8.1(7.6-10.2)19	8.0(7.3-8.3)18	7.8(7.7-7.9)2	8.1(6.9-8.7)12	8.1(7.5-8.9)11	8.2(7.8-8.5)13	8.1(7.7-8.7)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-31. TOTAL ALKALINITY ($CaCO_3$, mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE BELLE FOURCHE RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n[†]	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
4257	--	--	--	--	259(182-336)2	248(185-297)4	212(90-300)4	110(90-130)2
42578	--	--	--	--	292(-)1	189(87-317)7	220(52-430)8	206(98-410)3
4259	--	--	--	--	--	--	--	--
4264	--	--	--	--	--	--	430(295-506)4	315(74-610)5
4265	--	--	--	--	445(139-556)5	380(81-673)11	311(130-578)10	363(75-640)5
4278	182(75-281)11	186(93-289)12	180(127-237)12	206(153-299)12	187(115-287)12	192(107-263)12	196(139-271)13	158(90-254)3
4285	150(40-285)11	170(120-265)12	150(94-202)12	173(100-310)12	182(107-271)11	177(139-230)11	167(65-279)16	186(105-254)4
4295	--	--	--	215(-)1	--	--	--	--
4299	--	--	--	226(-)1	--	--	--	--
4305	--	--	--	--	--	--	--	--
4345	155(106-189)16	179(120-233)16	180(154-235)13	185(121-254)9	175(126-239)11	190(153-237)12	186(160-244)11	149(60-230)4
4367	--	--	--	244(-)1	--	--	--	--
4368	170(83-331)16	241(104-460)17	201(142-317)18	272(154-486)11	228(77-431)11	254(111-464)13	278(82-579)12	312(57-450)3
4370	157(121-241)20	194(106-349)17	191(143-404)21	222(135-460)11	209(94-356)11	213(121-354)13	219(110-383)10	197(66-320)5
4380	208(105-493)4	232(134-362)7	172(105-299)9	221(171-308)3	193(79-409)12	177(132-308)12	191(72-411)13	182(66-320)4

*For full description of station locations, see Table 26.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-32. SUSPENDED SEDIMENTS (mg/l), 1971-78, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE LITTLE MISSOURI RIVER BASIN

Station Number*	1971	1972	1973	1974	1975	1976	1977	1978
	$\bar{x}$ (min-max) n†	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n	$\bar{x}$ (min-max) n
3370	12373(2200-32299)3	12036(200-40399)9	4445(82-18800)8	126(81-183)3	7538(128-14600)7	2453(117-13100)6	3880(84-14100)7	6419(81-40399)43
4257	--	--	--	--	--	69(30-151)8	37(-)1	65(30-151)9
42578	--	--	--	--	--	925(3-3340)9	37(-)1	836(3-3340)10
4265	--	--	--	--	--	1766(12-7890)8	2098(106-10500)6	1908(12-10500)14
4305	310(24-1160)4	87(14-246)12	654(23-4990)12	256(22-1900)12	180(12-1700)13	48(19-86)10	62(18-152)9	230(12-4990)72
4370	--	--	--	--	--	21500(-)1	21500(-)1	--
4380	--	--	--	341(297-385)2	1022(144-4479)12	2155(202-7960)7	1335(144-7960)21	--

*For full description of station locations, see Table 26.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

APPENDIX C

PARAMETER ING WATER QUALITY CRITERIA

Contents of this appendix e organized by basin and station as described in Table 26 of this report.

Those parameters for which water quality criteria have been exceeded in the study area during the years 1974-77, and the maximum parameter value observed during those years, are listed for each station. Also presented are the number of violations observed for each parameter and beneficial use, and total number of data points collected per parameter during the specified time frame. Beneficial use codes presented represent the following:
AL=aquatic life, DW=drinking water, I=irrigation, L=livestock.

APPENDIX C

PARAMETERS EXCEEDING WATER QUALITY CRITERIA

Contents of this appendix are organized by basin and station as described in Table 26 of this report.

Those parameters for which water quality criteria have been exceeded in the study area during the years 1974-77, and the maximum parameter value observed during those years, are listed for each station. Also presented are the number of violations observed for each parameter and beneficial use, and total number of data points collected per parameter during the specified time frame. Beneficial use codes presented represent the following:
AL=aquatic life, DW=drinking water, I=irrigation, L=livestock.

TABLE C-1. PARAMETERS EXCEEDING WATER QUALITY CRITERIA IN THE BELLE FOURCHE AND LITTLE MISSOURI RIVER BASINS AND THE TOTAL NUMBER OF OBSERVED VIOLATIONS

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded													
	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chloride	Chromium	Copper	Cyanide	Dissolved Oxygen	Fluoride	Iron	Lead
Little Missouri River														
06335000														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	*17	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06335500														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	*16	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06336000														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	**3	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06337000														
AL	***	***	***	***	***	*20	***	**5	***	***	**1	***	*18	*20
DW	***	***	***	***	***	**4	***	**6	***	***	***	**4	*20	*20
I	**5	***	***	***	***	**4	***	**5	**5	***	***	**4	*11	***
L	**5	***	***	***	***	***	***	***	**2	***	***	**3	***	*20
TOTAL OCCURRENCES	**8	***	**1	**4	**8	*20	*39	*15	*20	***	*36	**8	*20	*20
MAXIMUM VALUE	20000.0	0.0	300.0	10.0	510.0	30.0	33.0	330.0	610.0	0.0	12.0	5.2	10000.0	500.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
Belle Fourche River														
06425720														
AL	***	***	***	***	***	**5	***	***	***	***	***	***	**1	**5
DW	***	***	***	***	***	**1	***	***	***	***	***	***	**5	**5
I	***	***	***	***	***	**1	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	**5
TOTAL OCCURRENCES	**5	***	***	**2	***	**5	**9	**3	**5	***	**9	***	**5	**5
MAXIMUM VALUE	2500.0	0.0	0.0	10.0	0.0	20.0	55.0	20.0	20.0	0.0	11.0	0.0	4700.0	200.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number, and Beneficial Use	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chloride	Chromium	Copper	Cyanide	Dissolved Oxygen	Fluoride	Iron	Lead
	Number of Times Criteria Exceeded													
06425780														
AL	***	***	***	***	***	**9	***	***	***	***	**1	***	**3	**9
DW	***	***	***	***	***	**1	***	***	***	***	***	***	**6	**9
I	**1	***	***	***	***	**1	***	***	***	***	***	***	**1	***
L	**1	***	***	***	***	***	***	***	***	***	***	***	***	**9
TOTAL OCCURRENCES	**9	***	***	**1	***	**9	*15	**3	**9	***	*15	***	**9	**9
MAXIMUM VALUE	26000.0	0.0	0.0	10.0	0.0	20.0	20.0	40.0	60.0	0.0	17.4	0.0	33000.0	100.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06425950														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06426400														
AL	***	***	***	***	***	**1	***	***	***	***	***	***	***	**1
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	**1
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	**1
TOTAL OCCURRENCES	***	***	***	***	***	**1	**3	**1	**1	***	**3	***	***	**1
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	10.0	230.0	5.0	10.0	0.0	15.2	0.0	0.0	100.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06426500														
AL	***	***	***	***	***	**8	***	***	***	***	**1	***	**5	**9
DW	***	***	***	***	***	***	***	***	***	***	***	***	**9	**9
I	**1	***	***	***	***	***	***	***	***	***	***	***	**1	***
L	**1	***	***	***	***	***	***	***	***	***	***	***	***	**9
TOTAL OCCURRENCES	**9	***	***	**3	***	**8	*25	**4	**9	***	*25	***	**9	**9
MAXIMUM VALUE	6700.0	0.0	0.0	10.0	0.0	10.0	170.0	10.0	30.0	0.0	12.6	0.0	8100.0	100.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06427850														
AL	***	***	***	***	***	**8	***	***	***	***	***	***	**4	*10
DW	***	***	***	***	***	***	***	***	***	***	***	***	**6	*10
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	*10
TOTAL OCCURRENCES	*10	***	***	**2	*23	**8	*48	**1	*10	***	*46	***	**9	*10
MAXIMUM VALUE	1300.0	0.0	0.0	10.0	290.0	10.0	30.0	10.0	20.0	0.0	12.0	0.0	1600.0	100.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number, and Beneficial Use	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chloride	Chromium	Copper	Cyanide	Dissolved Oxygen	Fluoride	Iron	Lead
	Number of Times Criteria Exceeded													
06428500														
AL	***	***	***	***	***	**1	***	***	***	***	***	***	***	**1
DW	***	***	***	***	***	***	***	***	***	***	***	***	**1	**1
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	**1
TOTAL OCCURRENCES	**1	***	***	***	**4	**1	*49	**1	**1	***	*18	***	**1	**1
MAXIMUM VALUE	680.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	360.0 UG/L	10.0 UG/L	32.0 MG/L	10.0 UG/L	20.0 UG/L	0.0 MG/L	12.8 MG/L	0.0 MG/L	880.0 UG/L	100.0 UG/L
06429500														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 MG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L
06429900														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 MG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L
06434500														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	*42	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	12.0 MG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 MG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L
06436700														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L	0.0 MG/L	0.0 MG/L	0.0 MG/L	0.0 UG/L	0.0 UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number, and Beneficial Use	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chloride	Chromium	Copper	Cyanide	Dissolved Oxygen	Fluoride	Iron	Lead
	Number of Times Criteria Exceeded													
06436800														
AL	***	***	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	*46	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	230.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06437000														
AL	***	***	***	***	***	***	***	***	***	**4	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	*44	***	***	**4	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	62.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L
06438000														
AL	***	***	***	***	***	*11	***	**4	***	***	***	***	**8	*11
DW	***	***	***	***	***	***	***	**4	***	***	***	***	**8	*11
I	***	***	***	***	***	***	***	**4	**3	***	***	***	**6	***
L	***	***	***	***	***	***	***	***	***	***	***	***	***	*11
TOTAL OCCURRENCES	***	***	***	***	***	*11	*39	*10	*11	***	**1	***	*10	*11
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	10.0	58.0	330.0	410.0	0.0	9.9	0.0	40000.0	500.0
	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	UG/L	MG/L	MG/L	MG/L	UG/L	UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded											
	Lithium	Manganese	Mercury	Molybdenum	Nickel	Nitrate-N	Nitrite-N	pH	Selenium	Silver	Sulfate	Zinc
• Little Missouri River												
06335000												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	*16	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	*14	***	*17	***	***	*17	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.6 MG/L	0.0 MG/L	8.8 SU	0.0 UG/L	0.0 UG/L	1000.0 MG/L	0.0 UG/L
•												
06335500												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	*14	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	*12	***	*16	***	**1	*16	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.6 MG/L	0.0 MG/L	8.8 SU	0.0 UG/L	1.0 UG/L	1100.0 MG/L	0.0 UG/L
•												
06336000												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	**3	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	**2	***	**3	***	**1	**3	***
MAXIMUM VALUE	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.0 UG/L	0.2 MG/L	0.0 MG/L	8.5 SU	0.0 UG/L	1.0 UG/L	1100.0 MG/L	0.0 UG/L
•												
06337000												
AL	***	***	*15	***	***	***	***	***	***	***	***	***
DW	***	*17	***	***	***	***	***	***	**1	***	*37	***
I	***	**9	***	***	**3	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**8	*20	*15	**7	**8	***	***	*39	*15	***	*39	*20
MAXIMUM VALUE	320.0 UG/L	11000.0 UG/L	1.2 UG/L	10.0 UG/L	650.0 UG/L	0.0 MG/L	0.0 MG/L	8.9 SU	11.0 UG/L	0.0 UG/L	1200.0 MG/L	1900.0 UG/L
• Belle Fourche River												
06425720												
AL	***	***	**2	***	***	***	***	***	***	***	***	***
DW	***	**5	***	***	***	***	***	***	***	***	**9	***
I	***	**5	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**5	**5	**2	**5	**5	***	***	**9	**2	***	**9	**5
MAXIMUM VALUE	310.0 UG/L	1400.0 UG/L	0.5 UG/L	3.0 UG/L	100.0 UG/L	0.0 MG/L	0.0 MG/L	8.4 SU	1.0 UG/L	0.0 UG/L	5400.0 MG/L	60.0 UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number and Beneficial Use	Number of Times Criteria Exceeded											
	Lithium	Manganese	Mercury	Molybdenum	Nickel	Nitrate-N	Nitrite-N	pH	Selenium	Silver	Sulfate	Zinc
•												
06425780												
AL	***	***	**1	***	***	***	***	***	***	***	***	***
DW	***	**8	***	***	***	***	***	***	***	***	*14	***
I	***	**5	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**9	**9	**1	**6	**9	***	***	*15	**8	***	*15	**8
MAXIMUM VALUE	80.0	2400.0	0.2	4.0	50.0	0.0	0.0	8.7	5.0	0.0	1900.0	260.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06425950												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06426400												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	**1	***	***	***	***	***	***	***	***	**3	***
I	***	**1	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**1	**1	***	**1	**1	***	***	**3	***	***	**3	**1
MAXIMUM VALUE	30.0	350.0	0.0	5.0	50.0	0.0	0.0	8.2	0.0	0.0	1200.0	30.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06426500												
AL	***	***	**2	***	***	***	***	***	***	***	***	***
DW	***	**9	***	***	***	***	***	***	***	***	*23	***
I	***	**6	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**9	**9	**2	**7	**9	***	***	*25	**3	***	*25	**9
MAXIMUM VALUE	70.0	1000.0	0.6	6.0	50.0	0.0	0.0	8.6	2.0	0.0	1600.0	70.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06427850												
AL	***	***	**1	***	***	***	***	***	***	***	***	***
DW	***	**7	***	***	***	***	***	***	***	***	*47	***
I	***	**2	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**9	**9	**1	**7	**9	*40	***	*44	**8	***	*48	**9
MAXIMUM VALUE	80.0	310.0	0.1	4.0	50.0	3.2	0.0	8.4	1.0	0.0	960.0	80.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number, and Beneficial Use	Number of Times Criteria Exceeded											
	Lithium	Manganese	Mercury	Molybdenum	Nickel	Nitrate-N	Nitrite-N	pH	Selenium	Silver	Sulfate	Zinc
•												
06428500												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	**1	***	***	***	***	***	***	***	***	*48	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	**1	**1	***	**1	**1	*34	***	*13	**1	***	*49	**1
MAXIMUM VALUE	90.0	140.0	0.0	2.0	50.0	3.2	0.0	8.3	1.0	0.0	1300.0	40.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06429500												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06429900												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06434500												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	*42	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	*36	***	***	*42	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	1000.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
•												
06436700												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	***	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	***	***	***	***	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L

(Continued)

TABLE C-1. (Continued)

Stream, Station Number and Beneficial Use	Lithium	Manganese	Mercury	Molybdenum	Nickel	Nitrate-N	Nitrite-N	pH	Selenium	Silver	Sulfate	Zinc
*												
06436800												
AL	***	***	***	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	*46	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	***	***	***	***	***	*43	***	***	*46	***
MAXIMUM VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	0.0	0.0	4300.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
*												
06437000												
AL	***	***	**4	***	***	***	***	***	***	***	***	***
DW	***	***	***	***	***	***	***	***	***	***	*43	***
I	***	***	***	***	***	***	***	***	***	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	***	**4	***	***	***	***	*39	***	***	*44	***
MAXIMUM VALUE	0.0	0.0	1.3	0.0	0.0	0.0	0.0	8.8	0.0	0.0	2100.0	0.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L
*												
06438000												
AL	***	***	**7	***	***	***	***	***	***	***	***	***
DW	***	*11	**1	***	***	***	***	***	**1	***	*39	***
I	***	**8	***	***	***	***	***	***	**1	***	***	***
L	***	***	***	***	***	***	***	***	***	***	***	***
TOTAL OCCURRENCES	***	*11	**7	***	***	***	***	*37	*10	***	*39	*11
MAXIMUM VALUE	0.0	29000.0	9.3	0.0	0.0	0.0	0.0	8.9	22.0	0.0	2300.0	1100.0
	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	MG/L	SU	UG/L	UG/L	MG/L	UG/L